

Technical Memorandum

Assessment of short-term impacts from a “worse case” release of Kettle Creek oil-tar sediments

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Executive Summary
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Executive Summary

A state-of-the-art computer model was set-up and run to study the potential impacts of Kettle Creek discharges on the near shore waters of Lake Erie at the Elgin Area Water Intake, five kilometres away. Complete wash-out of an historical deposit of oil-tar in creek sediment, located about one kilometre upstream of the lake, is assumed to be caused by an extreme storm event. Once in the lake, the movement of the oil-tar sediment plume eastward towards the water intake is assessed based on measurements in 2007 of near shore lake currents and weather conditions.

The model runs include several assumptions about sediment movement designed to ensure that a worse-case scenario is assessed to err on the side of safety. Four types of sediments and two sets of lake conditions are assessed to cover a range of outcomes. Although the Kettle Creek plume moving eastward in the lake is expected to stay within a few hundred metres of shore, the modeling assumes that the plume would spread more offshore since the water intake is a kilometre offshore.

The results show that the amount of sediment at the oil-tar deposit in the creek is about 9% of the estimated total suspended sediment discharged from the creek during the extreme storm event.

Oil-tar in sediment and sediment-laden water could reach the intake only in the unlikely event that the sediment does not settle out and the Kettle Creek plume spreads further offshore than expected based on experience. Using these worse-case assumptions the model estimates that the offshore edge of the Kettle Creek plume could reach the intake and oil-tar levels would elevate for about one to two days. The levels of oil-tar at the intake would be 23 to 55 times lower than those discharged from the creek. Since these estimates are based on worst case assumptions which are unrealistic they are intended for contingency planning purposes and not for actual estimates of risk.

The model runs of realistic conditions do not show any impact of the oil-tar deposit on the water intake. This is because the sandy sediments of the oil-tar deposit would settle out in the harbour or in the lake within one to two kilometres of the harbour, well before the location of the intake. Over the long-term, storm events would continue to mix this sediment into the extensive sediment of the lake bottom such that the attached oil-tar compounds (polycyclic aromatic hydrocarbons or PAHs) could not be distinguished from the normal background levels of sediment PAHs by the time the sediment did reach the intake.

Assessment of short-term impacts from a “worse case” release of Kettle Creek oil-tar sediments

Introduction:

The Southwestern Region (SWR) of the Ontario Ministry of the Environment (MOE), as part of its mandate, manages environmental issues within the Kettle Creek vicinity. One such issue is the potential movement of sediments which contain elevated levels of polycyclic aromatic hydrocarbons (PAHs); (these sediments were originally impacted via the operation of the former Oil Gasification Plant). In 2009, the SWR requested that the Environmental Monitoring and Reporting Branch (EMRB) of the MOE carry-out simulation modeling to examine potential impacts of these sediments, under extreme conditions. This information will assist them with their ongoing task of helping to protect drinking water supplies withdrawn from the Elgin Region intake, which is located about 5 km east of Port Stanley.

The Great Lakes Unit (GLU) of EMRB provides surface water simulation modeling in the Great Lakes and their connecting channels, in support of various programs. As part of this commitment, the GLU purchased the “MIKE3” modeling package in 2009. The MIKE3 modeling package was developed and is technically supported by the “DHI” Research Institute in Denmark. The model is an advanced, “state-of-the-art” software package used for simulating 3-dimensional “hydrodynamics” (i.e. water current velocities and temperatures), as well as the transport, dispersion and impact of various types of water quality parameters, within surface water bodies. The model itself is used widely around the world. More detailed information about it can be found from the DHI website (<http://www.dhigroup.com/>).

A key GLU application of the MIKE3 model is to assist with our Great Lakes Near shore monitoring program. Specifically, the model is being set-up to extend our understanding of various water quality field data collected within selected near shore sites along Ontario’s Great Lakes. This program is carried-out on a multi-year rotational basis by Dr. Todd Howell. In 2007, numerous such data was collected in the near shore vicinity of Kettle Creek. These data, along with various other external agency data, are being used in the initial application of MIKE3 model to Lake Erie.

The MIKE3 model utilizes “numerical” integration for solving various equations applied to small 3-dimensional divisions (layered elements) of the physical water body. As such, it requires a great deal of time to complete longer-term simulations. In order to apply the model with sufficient resolution (via use of sufficiently small divisions) to study the impact of Kettle Creek upon the near shore of Lake Erie, two (sequential) levels of application are utilized. These include: an initial “whole-lake” application, which is made to simulate the basic large lake-wide hydrodynamics, via use of coarser spatial elements; followed by a “nested” model application, in which only a small portion of the north section of the lake in the vicinity of Kettle, Catfish and Big Otter Creeks is examined, via use of much finer spatial elements.

The model does have sediment transport and bottom morphology change simulation capabilities, however to date, only the initial 3-dimensional hydrodynamic work stage has been initiated. The combined whole Lake Erie and nested Central Basin MIKE3 modeling work, as setup using 2007 measured conditions, is still ongoing. However, it is advanced enough to provide preliminary simulation capabilities to permit the assessment of the potential short-term impact of a hypothetical release of Kettle Creek oil-tar sediments, upon the Elgin Region intake.

MIKE3 model setup:

Whole-lake model:

(i) model grid:

The “whole-lake” model is setup in order to permit the simulation of all lake-wide phenomena. In the context of this report, this includes dynamic (i.e. time-variable) and spatially-variable changes to water: level, velocity and temperature; throughout the lake. A relatively coarse horizontal “grid” (i.e. made up of larger spatial elements) is used to reduce computer simulation times, however, the grid must be detailed enough to permit the simulation of key phenomena, (such as the development / variation of alongshore currents under various meteorological conditions throughout the year). The final grid selected via a lengthy testing process, consists of 3,384 horizontal spatial elements, and is shown in Figure 1.

Based on previous modeling results carried-out by the GLU in Lake Huron, a “sigma” layering system was used to define the vertical dimension of the model grid. Each horizontal spatial element was split into 10 layers, (regardless of depth). The thickness of these layers represented: 4, 8, 10, 12, 16, 16, 12, 10, 8, and 4%, sequentially, of the (dynamic) local water column depth of the spatial element.

(ii) input data:

The main drivers to changes in water level and 3-dimensional currents and temperatures in Lake Erie are: the basic dynamic meteorological conditions, including: spatially-variable wind and atmospheric pressure, as well as basic seasonal energy flux exchanges between the atmosphere and lake; and the hydraulic flows into and out of the lake. Data were collected for the December 1, 2006 through December 31, 2007 time period.

The pre-simulation software that comes with the MIKE3 package is used to create the necessary input data formats / files necessary for running the model, (after the data has been initially collected and organized). Since Lake Erie is particularly subject to seiche activity, (owing to its orientation and relative shallow depths), a spatially-variable, dynamic wind and atmospheric pressure input format is used. The actual measured data used by the MIKE3 pre-simulation software to derive the wind / pressure gradients

were obtained from about 16 stations located around Lake Erie. These data came from publicly accessible data-bases of Environment Canada and the U.S. Meteorological Service.

Estimated daily-average Detroit River inflow and Niagara River outflow were kindly supplied by the U.S. Army Corps of Engineers. Daily-average inflows from key U.S. tributaries were obtained from publicly accessible data-bases of the U.S. Geological Survey. Hourly flow data for Kettle, Catfish, and Big Otter Creeks, as well as the Grand River, were kindly provided by Environment Canada and local conservation authorities.

Nested model:

(i) model grid:

A detailed “nested” model is developed to cover the spatial extent of the nearshore vicinity of the Kettle / Catfish / Big Otter Creeks study area. A significantly finer horizontal grid resolution is used to permit a more accurate study of the interaction of the plumes from these creeks upon the Lake Erie nearshore. The extent of the nested model is defined by “open boundaries” (i.e. the water edges of the nested model within Lake Erie). The location of the nested model’s open boundaries were selected, via a testing procedure, such that: i) plumes from the 3 tributaries would largely remain within the study area during several typical alongshore current reversal periods, (to examine secondary plume impacts); ii) upwelling / downwelling events associated with deeper waters further offshore could be simulated accurately; and iii) instabilities associated with the geometric shape of the nested model could be avoided over longer simulation time periods.

The final “nested” model is shown as Figure 2. It consists of 2,745 spatial elements, and utilizes (as required by the MIKE3 software) the same vertical layering schematic, (i.e. the same 10 layer structure), as used by the whole-lake model. An enlargement of the nested model in the vicinity of interest for this assessment is shown as Figure 3. It includes the lower 1 km (approximate) section of Kettle Creek. The portion of the grid in Kettle Creek is relatively simplistic, with each element covering the entire creek width. It is designed to simulate the creek-wide water velocity and associated concentrations of soluble water quality parameters, as they enter the Port Stanley harbour, and subsequently interact with the open lake through the harbour’s east and south gaps.

(ii) open boundary conditions

The whole-lake model is run using measured boundary conditions (i.e. using the inflows / outflows, and all meteorological driving forces as described previously). For the nested model, however, the hydrodynamic conditions along each of its 3 open boundaries must be prescribed in detail, throughout the duration of the simulation. In this case, these were derived from the simulated whole-lake model results, using post-simulation MIKE3 processing software. These consisted of: (i) water levels at each of the 42 model nodes along the 3 open boundaries; and (ii) water temperatures and water

quality parameter concentrations extracted along the vertical plane (in each of the 10 layers) of each of the 3 open boundaries. All of these data were simulated at half-hourly time increments throughout the simulated year (of 2007).

Comparison of model results with measured data:

As discussed previously, the GLU collected numerous field data, including 3-dimension water current velocities and temperatures, at a few stations in the portion of the lake covered by the nested model from April through November in 2007. Data from the Kettle Creek Offshore site, (located about 5 km offshore), were used in performing sensitivity analyses and calibration for various modeling parameters, including: wind friction coefficient, bottom roughness, eddy viscosity, and energy-flux related parameters, (including short-wave radiation, vertical dispersion coefficients, and water column light penetration coefficients).

A comparison of model simulated water current velocities and temperatures at a couple of other measurement stations (i.e. stations not used in the calibration) are provided in Figures 4 and 5. In general the results show a good verification (i.e. statistically significant) of the MIKE3 model's performance. Most of the differences in water current and temperature dynamic episodes can be explained by likely differences in the actual local wind conditions, as compared with the wind field generated by the spatial interpolation scheme. This will be investigated further as part of the general GLU study ongoing. However overall, it can be concluded that the model simulates well the changes in basic current and temperature structures in the nearshore, during episodes of alongshore current reversals, which is important for tributary impact analyses.

A comparison of simulated and measured water surface elevation at the Environment Canada Port Stanley station is provided in Figure 6. As can be seen, the basic inputs to, and simulation of, the lake hydraulics appear correct.

Selection of "worse case" scenario:

Sediment lost during the worse case scenario event:

The MOE Southwestern Region provided the key sediment-loss parameters for consideration in this hypothetical worse case impact assessment. These included:

- *a loss of 1000 cubic metres of sediment deposit: grain size = sand*
- *Total PAH sorbed to sediment particles (no free phase)*
- *Sediment PAH average concentration of deposit = 23 ug/g*
- *Sediment PAH average ambient concentration in Kettle Creek = 2 ug/g*
- *Sediment PAH average ambient concentration in Lake Erie = 0.8 ug/g*
- *Creek discharge pro-rated (1.58x) from gauge station 02GC002 (Kettle Creek at St. Thomas)*
- *Creek storm event TSS average conc. = 200 mg/L*

While not specified, based on general past work it is likely that the in-situ density of sandy sediment is in the 1,200 to 2,000 kg/m³ range. To maximize (for safety) the size of potential oil-tar sediment lost, a 2,000 kg/m³ in-situ density is used, meaning that the total mass of oil-tar sediment assumed to be lost during the worse-case event is 2 million kg, (i.e. this is the dry weight of the lost sediment).

Kettle Creek runoff event:

The August, 1983 Kettle Creek runoff event, as estimated by the Kettle Creek Conservation Authority was used as the base runoff hydrograph for this assessment. This base hydrograph was pro-rated for the mouth of Kettle Creek, using the given ratio (of 1.58 times) above. The resulting final hydrograph used for this assessment is shown in Figure 7.

Suspended sediment concentrations:

As discussed previously, a formal sediment transport modeling data base has not yet been set-up for the MOE MIKE3 model. As such, it is necessary to simulate the lost sediment from the oil-tar (as specified above), as a unique parameter, (i.e. to not consider its interaction with either the other background Kettle Creek suspended sediment likely generated during the runoff event, or any resuspended sediment within the nearshore of the lake). This decision both simplifies the assessment, and provides results of greatest importance, namely the potential direct impact of the oil-tar impacted sediments upon the drinking water intake. It is also a conservative assumption, since any settling and resuspension of Kettle Creek sediment with ambient harbour sediment or sediment within the lake nearshore, will tend to greatly dilute PAH levels within the resulting sediment mixtures.

The procedure followed in deriving the suspended sediment concentration function for the oil-tar sediment assumed lost during the storm event, is as follows:

- (i) Preliminary field data collected by the MOE-GLU and KCCA during 2007 and 2009 were used to obtain a very approximate relationship for (total) suspended sediment concentration as a function of Kettle Creek discharge. The relationship used measurements made during periods of larger flow-rate, (defined simply as when the flow-rate was above the approximate median 2009 flow-rate of about 1.6 m³/s). Based on this segregation of measured data, a simple linear relationship was derived as follows:

$$C_{SS} = 78.4 + 7.59 \cdot Q_{KC} \quad \dots 1$$

where: C_{SS} = total suspended sediment concentration, (mg/L); and
 Q_{KC} = Kettle Creek flow-rate at the St. Thomas gauge, (m³/s).

The correlation coefficient of this equation is 0.89, based on 29 points;

- (ii) The total suspended sediment mass discharged for the event was calculated, (i.e. which is simply the product of Kettle Creek flow-rate and total suspended sediment concentration);
- (iii) The total suspended sediment concentration time-series from step (i) was multiplied by the ratio of: mass of oil-tar associated sediment lost / total Kettle Creek suspended sediment mass discharged during the run-off event of step (ii); to produce the final oil-tar loss suspended sediment time-series; or in equation form:

$$[C_{CTSS}]_t = \{ M_{CTS} / M_{CKCTS} \} \cdot [C_{KCSS}]_t \quad \dots 2$$

where:

- $[C_{CTSS}]_t$ = time-series of concentration of oil-tar associated suspended sediment, (mg/L);
- $[C_{KCSS}]_t$ = time-series of concentration of total Kettle Creek suspended sediment, (mg/L);
- M_{CTS} = total mass of oil-tar associated sediment assumed to be lost during the worse case event, (kg); and
- M_{CKCTS} = total mass of (total) suspended sediment discharged from Kettle Creek during the runoff event, (kg).

A plot of the estimated total Kettle Creek suspended sediment concentration, (i.e. based on Equation 1), and the hypothetical worse case oil-tar associated suspended sediment concentration (i.e. using Equation 2); are shown in Figure 8.

The hypothetical total mass of oil-tar associated sediment of 2,000 tonnes as described earlier, would represent only around 9% of the estimated total suspended sediment discharged from Kettle Creek during the large runoff event. The time-averaged suspended sediment concentration during the overall runoff event, (which lasts about 74 hours), would be about: 600 and 50 mg/L; for the total Kettle Creek and hypothetical oil-tar sediments, respectively.

Behaviour of suspended sediment within the harbour and lake:

The MOE Southwestern Region has indicated that the oil-tar PAH is adsorbed onto sand grain-sized sediment. As such, it is expected that any released sediment, (as caused by erosion / resuspension within Kettle Creek during the worse case hydraulic event), would be subject to significant resettlement, after the Kettle Creek plume enters the relatively tranquil waters of the Port Stanley Harbour and (subsequently) the Lake Erie nearshore (outside of the surf zone where the intake is located). While it is not yet possible to directly simulate sediment transport with the MOE MIKE3 model, it is possible to (indirectly) approximate the effect of suspended sediment settlement, using the first-order loss-rate coefficient algorithm that exists within the hydrodynamic / dispersion algorithms of the hydrodynamic module of the model. This is possible owing

to the direct dependence of both: first-order (chemical) loss-rate and general loss of any given suspended sediment via settling; to the length of exposure time within the water column.

An approximate first-order loss-rate for suspended sediment is derived as follows:

- (i) The grain-size of sand is obtained using relevant literature values;
- (ii) The settlement velocity is estimated using the 3-part equation that the MIKE3 sediment transport algorithm uses for fine sand settling:

$$w_s = (s - 1) \cdot g \cdot d^2 / (18 \cdot \nu) \quad \dots \text{when: } d < 100 \text{ } \mu\text{m};$$

$$w_s = (10 \cdot \nu / d) \{ [1 + (0.01 \cdot (s - 1) \cdot g \cdot d^3) / \nu^2]^{0.5} - 1 \} \quad \dots \text{when: } 100 < d < 1,000 \text{ } \mu\text{m}; \text{ and}$$

$$w_s = 1.1 [(s - 1) \cdot g \cdot d]^{0.5} \quad \dots \text{when: } d > 1,000 \text{ } \mu\text{m};$$

where:

- w_s = settling velocity, (m/s);
- s = specific gravity of the sediment particle;
- d = grain size of the sediment particle, (m);
- ν = kinematic viscosity of water, (m^2/s); and
- g = the gravitational acceleration, (9.81 m/s^2).

- (iii) An approximate average water column depth is selected, (i.e. the temporal average water depth that the plume is exposed to while traveling from the Kettle Creek mouth to the intake vicinity);
- (iv) An assumption is made that the equivalent “half-life” for the suspended sediment to remain in the water column is equal to: half of the water depth, (from step (iii)), divided by the settling velocity for the sediment type, (from step (ii)); and
- (v) The equivalent first-order loss-rate for the sediment type within the water column is solved for using the half-life of step (iv).

In order to ascertain the overall sensitivity of the assessment results to sediment grain size (and the resultant settling from the water column), a total of 4 sediment types were considered. In sequential order from coarse to fine grain size, these include: very fine sand, median-size silt, fine silt, and Non-loss (or conservative behaving sediment that does not settle). The results of this procedure are summarized in Table 1.

Adjustment of Kettle Creek suspended sediment concentrations for sediment types:

For the ease of making model simulations for this assessment, the time-series used for the Kettle Creek flow-rate and the suspended sediment concentration for all 4 sediment types, are applied as “boundary conditions”; that is, at the upstream end of the portion of the model grid used to represent Kettle Creek, (which is about 1 km upstream from the mouth of the creek). However, for the purposes of evaluating the worse case scenarios, it is assumed that no resettlement of any of the eroded / resuspended oil-tar sediments can occur until the Kettle Creek plume enters the harbour, (i.e. passes by the mouth of the creek). This, as discussed earlier, is based upon the realistic assumption

that conditions would be too turbulent within Kettle Creek during the worse case runoff event to permit resettling there, but significantly less so in the harbour and non surf zone of the lake nearshore, (so as to permit resettling in these areas).

The first-order loss-rate algorithm used by MIKE3 can be either constant in time and space, or time-variable, but not spatially variable, which is the needed requirement to meet the condition described above. As such, it was necessary to artificially increase the oil-tar suspended sediment concentrations (as applied 1 km upstream from the mouth of Kettle Creek), so as to make up for sediment that the model would simulate as being lost as the plume traveled the 1 km distance down to the mouth of Kettle Creek. Specifically, the adjustment was made to make sure that the total suspended sediment leaving the mouth of Kettle Creek was equal to that predefined for the worse case scenario; (namely 2 million kg as estimated previously to equate to 1,000 m³ of loss oil-tar sediment).

This adjustment is required (uniquely) for each of the 3 non-conservative sediment types, (i.e. very fine sand, median silt, and fine silt), since the settling velocity estimated for each type of sediment is different. The adjustment factors were obtained by making preliminary simulations using the initial concentration time-series, (as applied at the upstream Kettle Creek boundary), and tracking the resulting actual suspended mass flux passing by the mouth of Kettle Creek during the simulation. The suspended concentration function applied at the upstream boundary was then increased by the ratio of: 2 million kg, divided by the total Kettle Creek mouth mass-flux value obtained during the preliminary simulation. The resulting factor was approximately: 1.01, 1.07 and 1.88; for fine silt, median silt and very fine sand, respectively.

Lake Erie hydrodynamic conditions:

Setting-up the whole-lake and nested simulation modeling data-sets discussed previously required a great deal of field data, time and effort. As such, instead of setting up a new fictitious Lake Erie modeling data-set for use with the worse case Kettle Creek discharge, it was decided to select appropriate simulated conditions already setup and tested, (as based on 2007 conditions in the lake). In other words, the hypothetical worse case loading scenario described above, and the Kettle Creek plume that it generated, were superimposed upon selected actual 2007 hydrodynamic events in the lake.

The Elgin Region drinking water intake is located to the east of Port Stanley. As such, the following simple criteria needed to be met in the selection of appropriate lake events for use with this assessment:

- (i) The existence of alongshore currents, well established, moving towards the east;
- (ii) These currents must persist long enough, to assure that the Kettle Creek plume would travel at least the approximate 5 km distance to the east, (or more);
- (iii) The episode took place during seasons of well vertically mixed conditions in the lake, (i.e. early spring, late fall, etc.); and

- (iv) (If possible), 2 separate eastward moving alongshore current episodes, with differing approximate current speeds, would be considered.

Obviously, criteria (i), (ii) and (iii) are essential to create potential impacts at the intake. Criteria (iv) helps to examine the possible sensitivity of the simulated impact to the effects of differing ambient lake advective / dispersive behaviour, (as brought about by differing mean current speeds and associated plume travel times).

The alongshore currents as simulated by the nested MIKE3 model between 1 March and 12 April 2007, at a point about a kilometer south of Port Stanley and at the Elgin Region intake, are shown in Figure 9. It is interesting to note that during this 6 week time period, there were approximately 14 alongshore current reversals, (in this case arbitrarily defined as a reversal of alongshore currents equal to or greater than 4 cm/s in magnitude). This implies average episode durations of about 3 days, (although there is obviously a great deal of variability in this value).

Two relatively well established, eastward moving, alongshore current episodes are seen within the first two weeks of March; namely starting on March 2nd and 10th. Further, these episodes possess different basic average current speeds, (of about 18 and 5 cm/s, respectively), and also occur in early March assuring vertically well-mixed lake conditions. As such, the potential impact from the worse case release of oil-tar sediments was simulated separately for both of these eastward moving lake episodes. The two simulations are referred to as Release 1 and Release 2, for the March 2nd and 10th release dates, respectively.

Dispersion in the lake:

The flow from Kettle Creek will tend to be quickly deflected and travel parallel to the general shoreline under the influence of typical alongshore currents in Lake Erie. (This has been previously noted in studies of similar other creeks / small rivers discharging into the near shore of the Great Lakes). However, the plume will then be gradually dispersed in the offshore direction as it is moved by the general alongshore current within the lake. The Elgin Region intake is located over a kilometer offshore, approximately 5 km east of Kettle Creek. As such to evaluate potential impacts upon the intake it is important to simulate the offshore dispersion of the Kettle Creek plume as it travels along the lake's shoreline, (i.e. under an eastward moving alongshore current condition in the lake).

The dispersion coefficient used by MIKE3 to describe the spreading of water column materials, (in our case suspended sediment), is based on a ratio of simulated "eddy viscosity", which is an empirical means used by the model's algorithms to simulate the generation and dissipation of turbulence within the water column, and their effect upon the resulting water velocity field. The value selected in the applications to date, are based upon values used in past work, and should be relatively accurate. However, to "err on the side of safety", the size of this ratio in the horizontal dimension was increased four-fold, meaning that if anything, the simulated rate of spreading of the

plume in the offshore direction will be somewhat greater than what would actually occur. This means that the simulated levels at the intake will tend to be greater than what likely would occur.

Simulated impacts from the worse case release:

Two basic types of simulated results are provided to help delineate the potential impacts of the worse case sediment release. These include: detailed suspended sediment concentration time-series at the Elgin Region intake, (and other specific intermediate points of interest), which show how the plume impacts a given location over time; and plan view “snap shots”, which show the overall extent of the plume at a given time after each release.

Concentration time-series results:

A plot showing the concentration of oil-tar suspended sediment versus time, are provided for 5 locations showing the progression of the resulting plume. These include at: the mouth of Kettle Creek; the east gap of the harbour; the south gap of the harbour; the shore of an imaginary north-south transect line which runs through the Elgin Region intake, (referred to as “Elgin at shore”); and at the (offshore) Elgin Region intake itself. These time-series are shown for each sediment type; namely: Figures 10, 11, 12, and 13; for fine sand, medium silt, fine silt and No Loss, respectively. Further, these results are shown separately for the two releases, as designated by “R1” or “R2”. *(As examples of the figure nomenclature: Figure 10R1 shows the concentration time-series at the five locations for Release 1, for a sediment release made up of “fine sand”; whereas Figure 13R2 shows those from Release 2 assuming “No Loss” (or conservative behaving suspended sediment)).*

To provide additional detail at the Elgin Region intake itself, two separate plots are provided as Figures 14 and 15; for concentrations of oil-tar suspended sediment and PAH (i.e. the equivalent PAH associated with the suspended sediment in whole-water), respectively. The curves associated with each of the 4 separate sediment types are shown together on each plot. A separate plot is used for Release 1 and 2.

The peak impact concentrations obtained via the simulations for both releases are also summarized numerically in Table 2, along with some basic travel time information.

Plan-view “snap shots” of the plume:

For each release, a series of 8 snap shots delineating the plume between Port Stanley and the Elgin Region intake have been generated. These are shown as: Figures 16a through 16h for Release 1; and 17a through 17h for Release 2. On each of the 8 figures (of both releases), there are 3 separate plots presented, designated as follows: (a) is the suspended sediment plume of the released oil-tar sediment assuming a fine sand grain size and subsequent settling behaviour within the water column (the expected case); (b) is the suspended sediment plume of the released oil-tar sediment

assuming no loss from the water column (the worse case behaviour); and (c) is the existing water velocity within the lake at the given time.

The two suspended sediment concentrations are taken from the bottom layer (of 10 total layers) in the water column. There is not a great deal of difference within the concentrations from the different layers, however, levels are slightly larger at the Elgin Region intake within the bottom layer, and as such, it was selected for overall presentation purposes. The water velocity is taken from Layer 6, which is located slightly above mid depth within the water column. There is a more significant difference in the water velocity among the different vertical layers, however, the mid-depth tends to well reflect the overall advective alongshore current condition, and as such, it was selected for presentation purposes.

The times selected for the snap shots are referenced with respect to the time when the centre of the oil-tar plume is located at the mouth of Kettle Creek. This permits a direct reference of results with the mean travel time of the plume. (Note that 1 or 2 of the first snap shots in the two series are taken before the centre of the plume reaches the mouth of Kettle Creek. These snap shots help delineate the entry of the “early stage” of the plumes into the lake.

In terms of positions, the Elgin Region intake (while not marked on the plots) is located at the very south-east corner (i.e. lower-right corner) in all plots of all results of Figures 16 and 17. The numbers along the “y-axis” and “x-axis” (of all plots) are the UTM Northings and Eastings, respectively, all in metres.

The results of the snap shot plots are essentially self-explanatory, and are discussed in the summaries below.

Summary of fine sand sediment type impacts:

The results show, (see Figures 10R1 and 10R2), that for a fine sand (or coarser) sediment type, (which is the sediment size of concern for the oil-tar impact), there would be no direct (i.e. from the actual water column plume itself) impact from either release upon the Elgin Region intake. This is assured by the relatively rapid rate at which the fine sand settles from the water column (to the bottom sediment layer). In fact, by summing the mass-flux of sand crossing both harbour gaps (and thus exiting to the lake), it appears that approximately 60% of the sand which enters the harbour from Kettle Creek would settle within the harbour itself, (and not make it into the lake).

As shown in the snap shot series of Figures 16 and 17, the remaining fraction entering the lake appears to settle from the water column (to the lake bottom) within one to two kilometers or so of the harbour. Owing to the assumptions made, it is reasonable to assume that the actual settlement distance would tend to be even shorter than this.

Summary of no loss sediment type impacts:

Figures 13R1 and 13R2 provide the simulated results for the “no loss” (or conservative behaving) sediment type for Release 1 and 2. For this sediment type, although the peak concentration at both gaps is generally similar to that at the mouth of Kettle Creek, by using the same mass-flux analysis as discussed above, it is estimated that approximately 95% of the oil-tar sediment would enter the lake via the south harbour gap. This reflects the relatively strong southward flow momentum created by the large Kettle Creek discharge. The remaining 5% enters the lake via the east harbour gap. (Note again that for this sediment type behaviour assumption, no sediment is lost to the harbour or lake beds).

The peak concentration seen at the “Elgin at shore” location is approximately 1/3 and 1/2 of that at the mouth of Kettle Creek, for Releases 1 and 2, respectively. This difference is primarily due to the fact that the quantity of ambient lake water that the plume mixes into is higher for Release 1, (i.e. as the current speed is over 3 times faster), meaning a greater rate of mixing.

The peak oil-tar suspended sediment concentration at the Elgin Region intake is around 4 and 9 mg/L, for Release 1 and 2, respectively, (see Figures 14R1 and 14R2). The equivalent, (suspended sediment-based, whole-water), PAH concentration for these two values is about 80 and 200 ng/L for Release 1 and 2, respectively, (see Figures 15R1 and 15R2). These levels are much smaller than the level which enters the harbour from Kettle Creek, (i.e. representing an equivalent Kettle Creek dilution factor of about 55 and 23 times, respectively for Release 1 and 2).

The duration of elevated concentration level at the intake would be about 3/4 of a day for Release 1, and 2 days for Release 2.

One interesting note for Release 2 is that there would be a second smaller impact at the intake as the plume passes by a second time owing to the alongshore current reversal (i.e. with currents moving westward) that takes place around the March 16-17 time period, (see Figures 9 and 14R2). However, owing to ongoing larger scale dispersion in the lake, peak levels would have been reduced by approximately a factor of 4 times for this secondary impact.

As is shown by the snap shot figure series for a “no loss” behaving plume, the Elgin Region intake is impacted by the outer (i.e. south) portions of the plume. In general, owing to the nature of numerical dispersion algorithms and grids used by the numerical models, the outer location (and associated concentration) of any plume tends to be somewhat less certain. Based on the use of the larger lateral dispersion coefficient (as discussed earlier) in producing the simulated results in this assessment, it is possible that the simulated concentrations at the intake may tend to be on the large size. However, until a more detailed analysis can be completed, (with the help of field data, etc.), the values presented in the time series figures and Table 2 should be used, if need be, for contingency planning.

Conclusions:

An initial application of the MOE MIKE3 model has been completed. It should provide reliable preliminary information as to the potential for a worse case oil-tar sediment release from Kettle Creek to impact the Elgin Region intake. A total of four assumed sediment type behaviours within the water column have been considered, ranging from the two extremes of: fine sand size and associated settling, to the very conservative assumption of “no loss” (from the water column).

Actual expected case:

Release of any fine sand sized (or coarser) sediment from the oil-tar impact area, (the expected size), will not directly reach the Elgin Region intake. A significant portion (of around 60%) of this released sediment mass would likely settle within the harbour, (owing to the relatively fast settling velocity of this type of material within the water column).

The remaining fraction entering the lake would settle likely within one or two kilometers of the harbour. This fraction would subsequently be mixed, over a period of several months and years, with the large amount of existing sediment on the lake bottom between the harbour and intake, during lake storm events. It can be easily shown, (i.e. using a simple mass balance mixing approach), that PAH within this subsequently mixed oil-tar / lake sediment would not be easily discernable, when compared with existing general background PAH values in the lake vicinity, by the time it reached the intake.

Worse case: If all released oil-tar sediment were to remain in suspension indefinitely, (as a worse case assumption), peak levels of suspended sediment at the Elgin Region intake would be under 10 mg/L, (based on two ambient lake eastwardly alongshore current regimes, with average speeds of about 18 and 5 cm/s). This is compared with peak oil-tar suspended sediment levels of around 200 mg/L leaving Kettle Creek. Equivalent, whole-water peak concentrations of PAH associated with these suspended sediment levels, would be less than approximately 200 ng/L. The duration time of these elevated levels at the intake would typically be in the order of 1 to 2 days.

Table 1. Sediment types considered.

Sediment Type:	Property of sediment grain:		Approximate settling characteristics:		
	specific gravity	grain-size (microns)	Settling Velocity (m/s)	Time for 50% settlement (hr)	Equivalent first-order loss-rate (1/s)
very fine-size sand	2.65	63	2.31E-03	0.6	3.21E-04
median-size silt	2.65	20	2.31E-04	6.0	3.21E-05
fine-size silt	2.65	4	9.03E-06	153.8	1.25E-06
NO settlement (conservative)	n.a.	n.a.	0	n.a.	0
<p><i>Notes:</i></p> <p>1. Calculations are based upon an ambient water temperature of 5° C.</p> <p>2. A larger than actual water depth of 10 m is used, to over-estimate settling time and under-estimate the equivalent first-order loss-rate.</p>					

Table 2. Summary of simulated impacts for Releases 1 and 2.

Sediment Type	Release Number	Location	Peak Concentration		Approximate time AFTER peak at mouth of Kettle Creek (hours)
			oil-tar suspended sediment (mg/L)	PAH (equivalent whole-water) (ng/L)	
fine SAND (likely case)	1	mouth Kettle Creek	226	5,198	0
		Harbour - South gap	122	2,806	0.25
		Harbour - East gap	34	782	0.75
		Elgin transect - shore	0	0	n.a.
		ELGIN INTAKE	0	0	n.a.
		ELGIN INTAKE later flow reversal	none	none	n.a.
	2	mouth Kettle Creek	227	5,221	0
		Harbour - South gap	123	2,829	0.25
		Harbour - East gap	27	621	0.75
		Elgin transect - shore	0	0	n.a.
		ELGIN INTAKE	0	0	n.a.
		ELGIN INTAKE later flow reversal	0	0	n.a.
NO LOSS from water column (worse case)	1	mouth Kettle Creek	197	4,531	0
		Harbour - South gap	195	4,485	0.50
		Harbour - East gap	189	4,347	1.50
		Elgin transect - shore	68	1,564	5.25
		ELGIN INTAKE	3.6	83	4.25
		ELGIN INTAKE later flow reversal	<i>no impact</i>	no impact	<i>n.a.</i>
	2	mouth Kettle Creek	197	4,531	0
		Harbour - South gap	195	4,485	0.50
		Harbour - East gap	188	4,324	1.75
		Elgin transect - shore	110	2,530	16.75
		ELGIN INTAKE	8.6	198	21.25
		ELGIN INTAKE later flow reversal	2.1	48	156.25

Notes:

1. The **ELGIN INTAKE** value is the impact caused directly by the primary Lake (eastward) current episode; the "**ELGIN INTAKE later flow reversal**" is the largest impact from the plume as it returns DURING the subsequent lake current reversal towards the west.

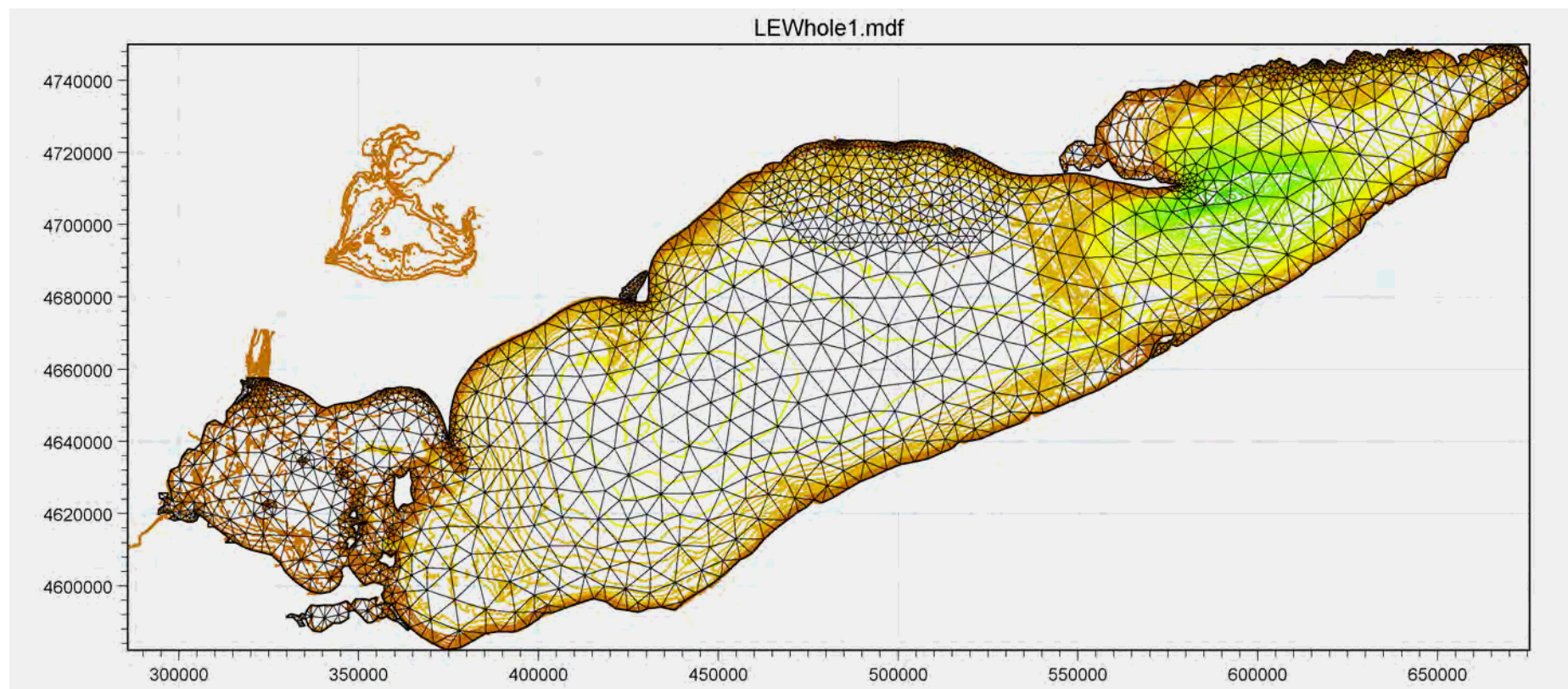


Figure 1. Whole-lake grid used for the MOE MIKE3 Lake Erie model.

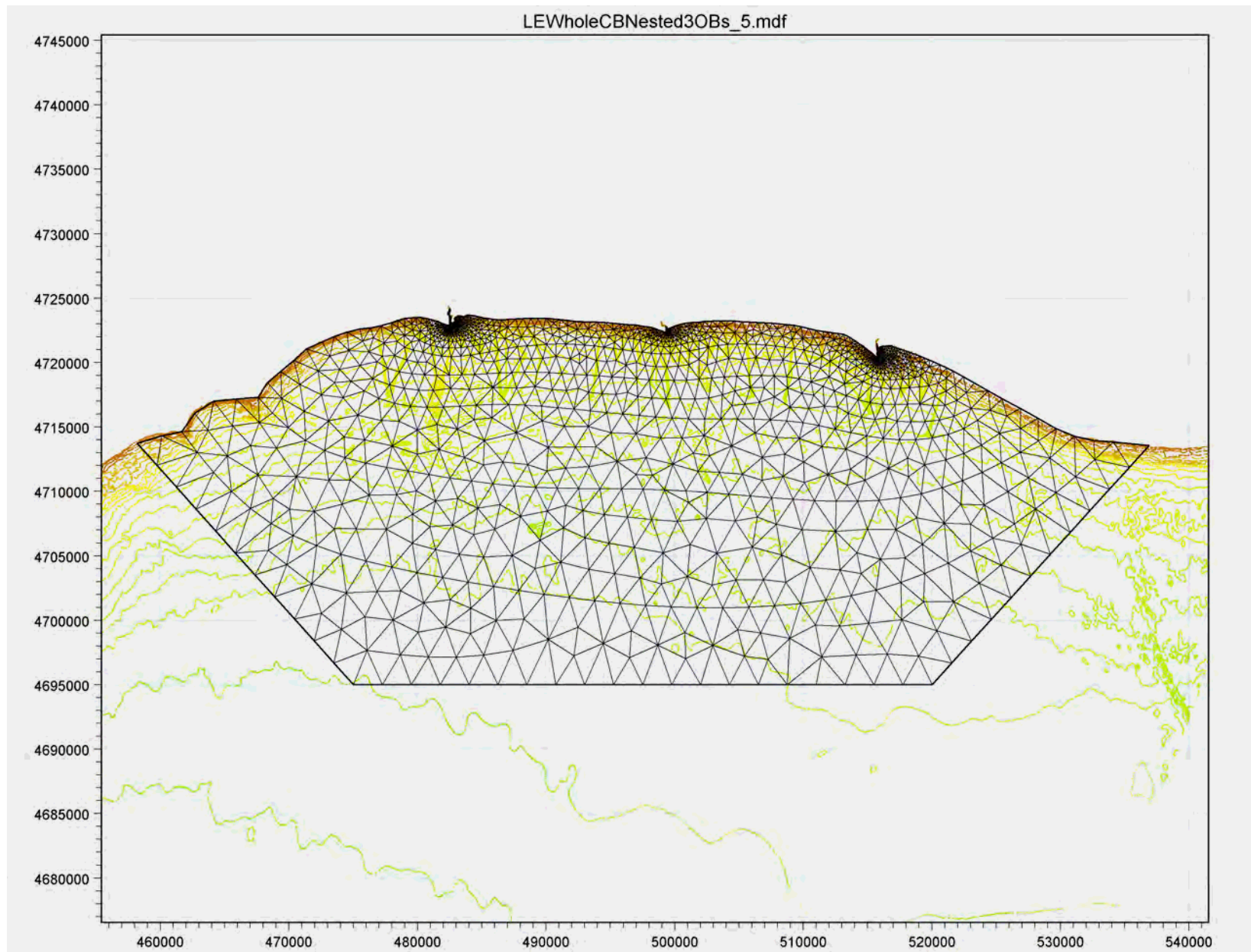


Figure 2. Nested model used for study of Kettle, Catfish and Big Otter Creek impacts upon Lake Erie.

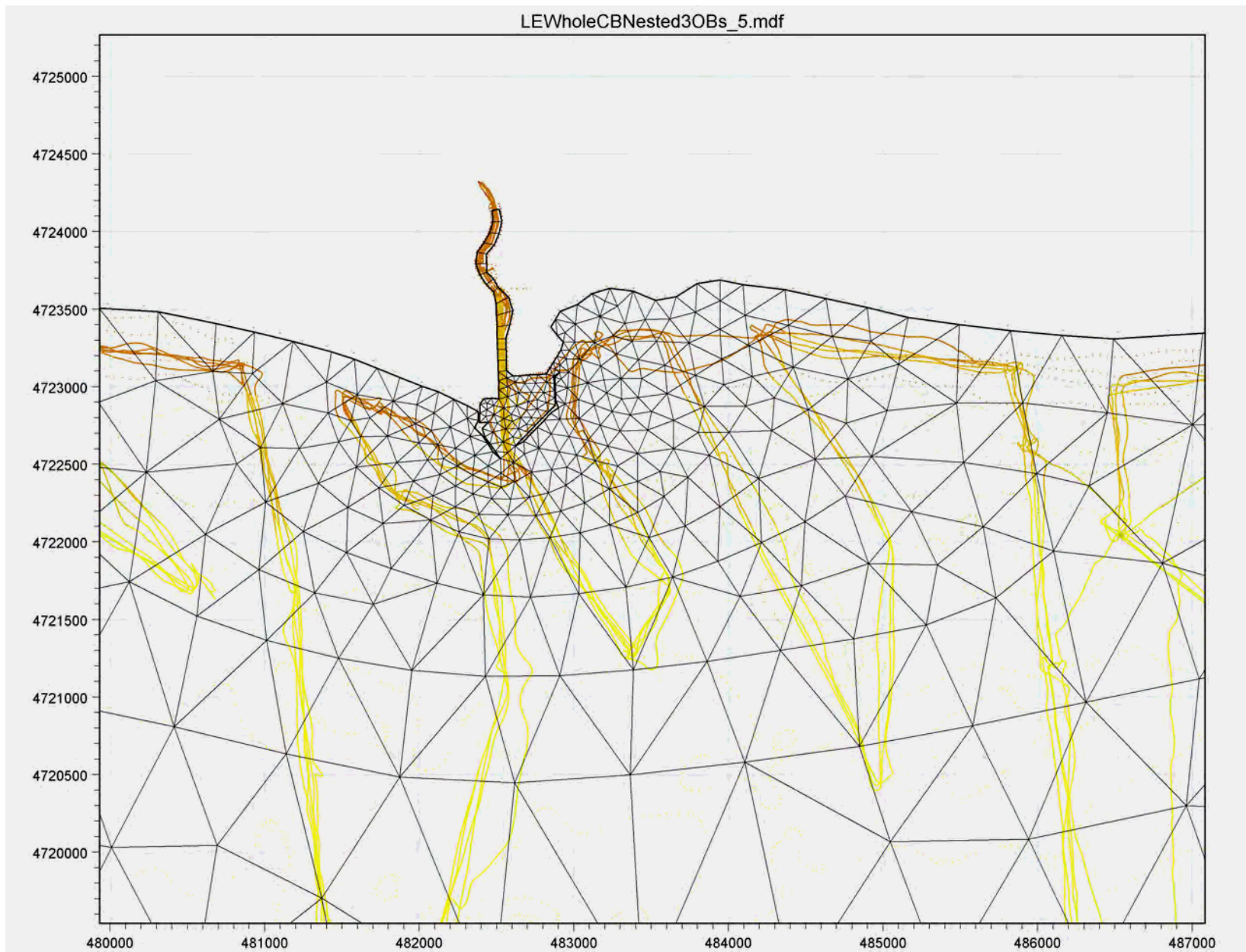


Figure 3. Enlargement of the nested model in the vicinity of Port Stanley.

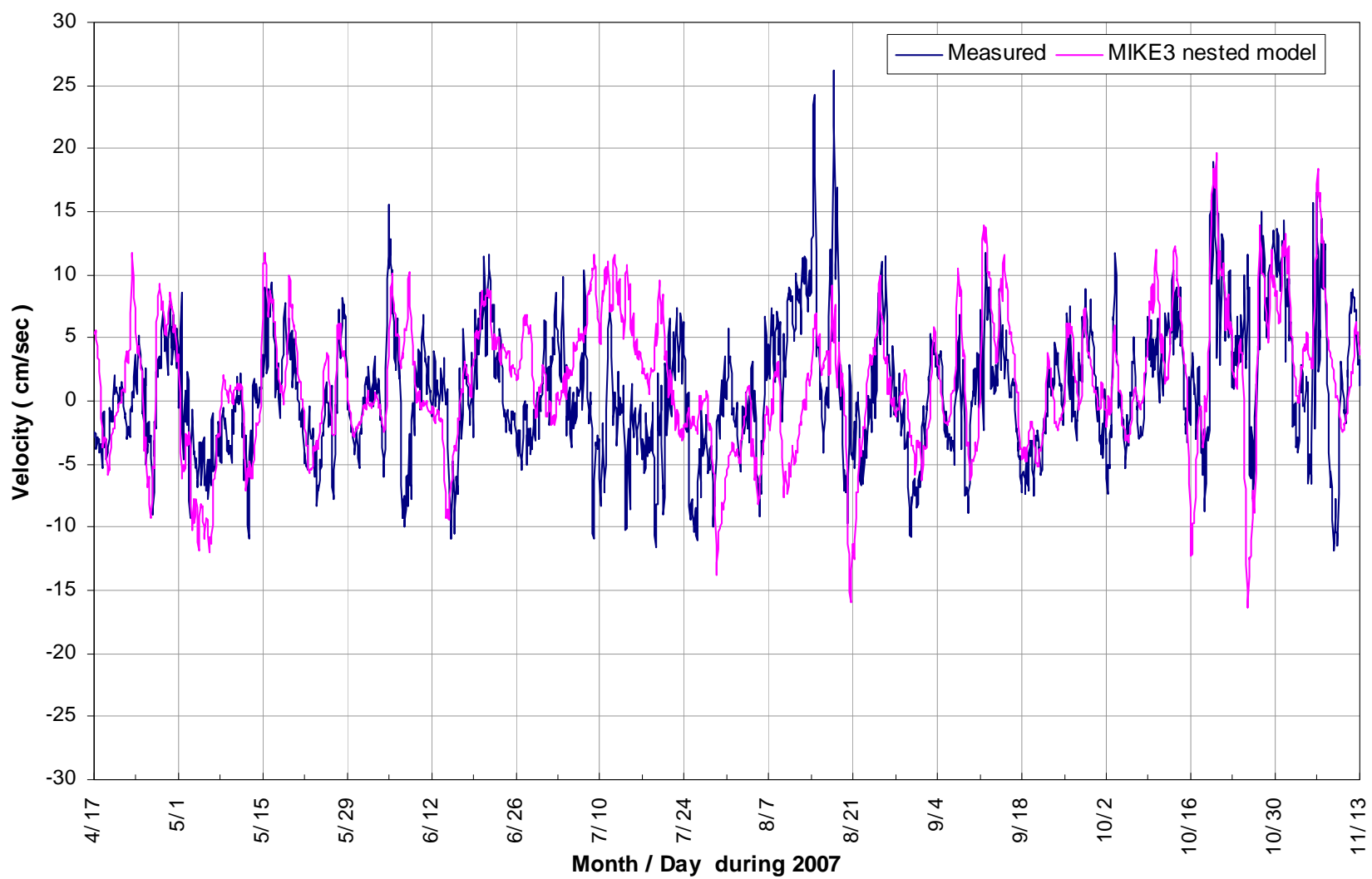


Figure 4. Alongshore depth-averaged velocity component @ GLU "Kettle Creek Midshore" Station

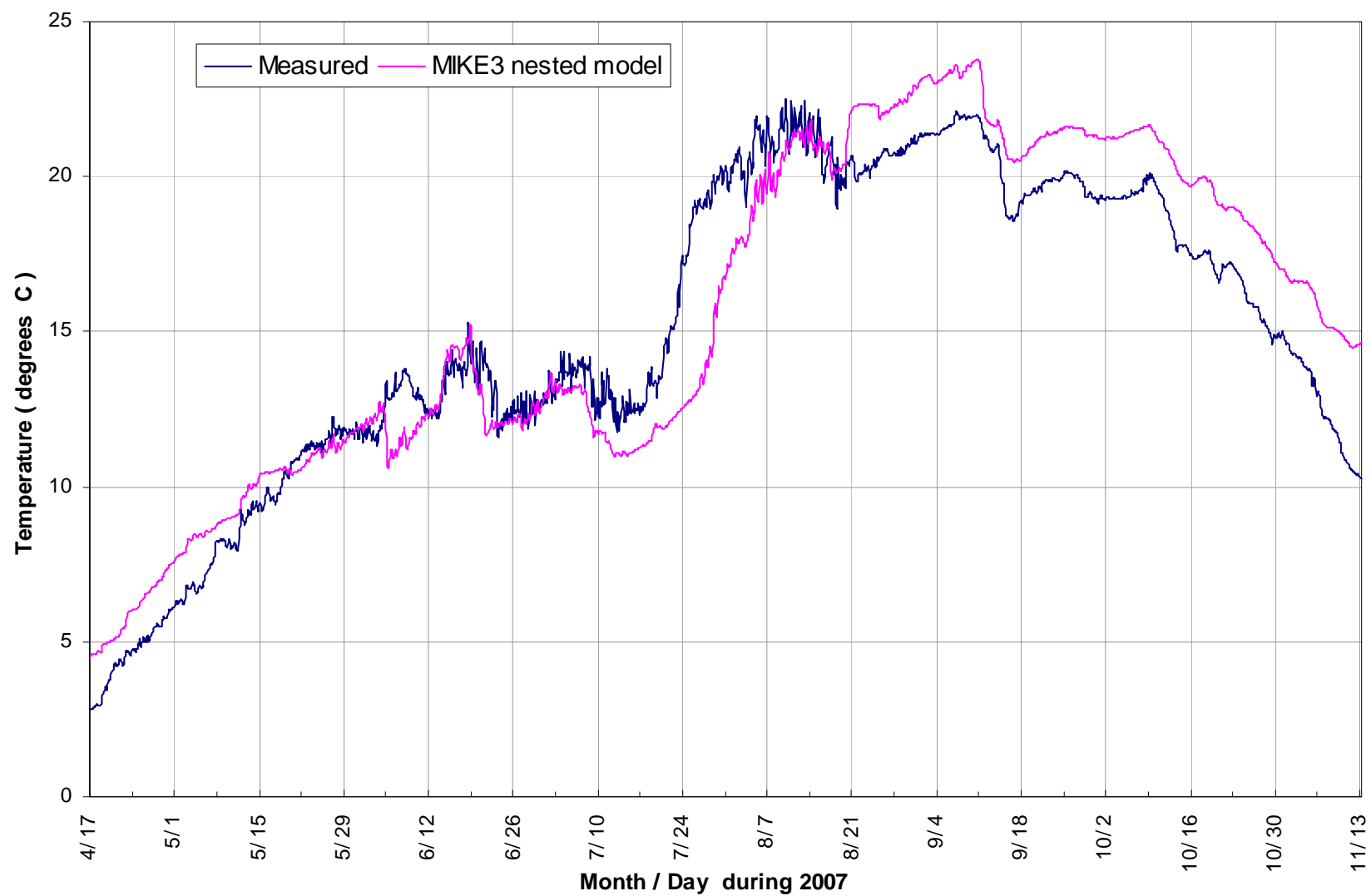


Figure 5. Depth-averaged temperature @ GLU - "Catfish Creek Offshore" Station

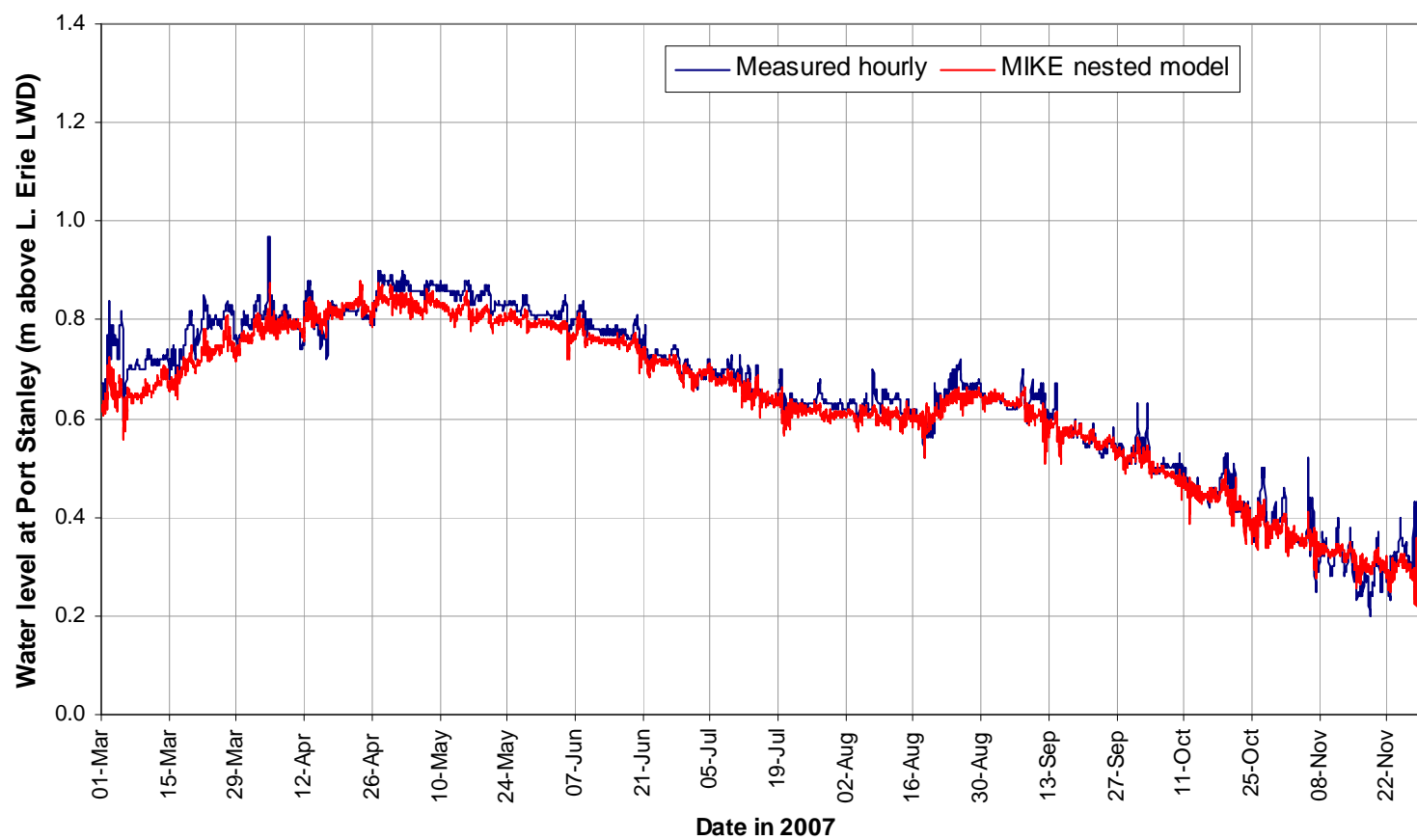
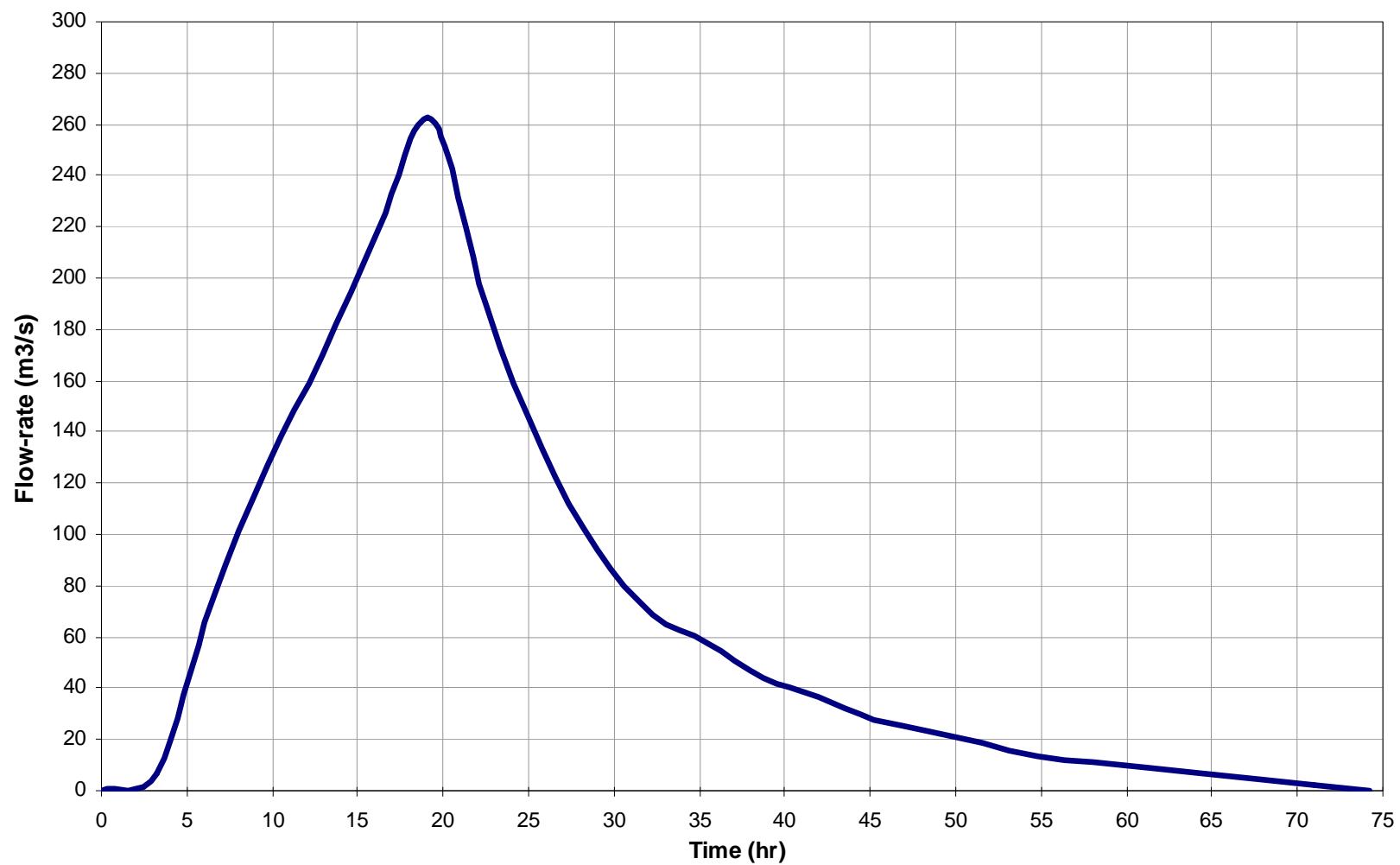


Figure 6. Lake Erie Water Levels at Port Stanley - 1 March to 1 December, 2007



**Figure 7. Hypothetical storm hydrograph for "worse-case" Kettle Creek event
(based on pro-rated, August 11-13, 1985 event measured at St. Thomas)**

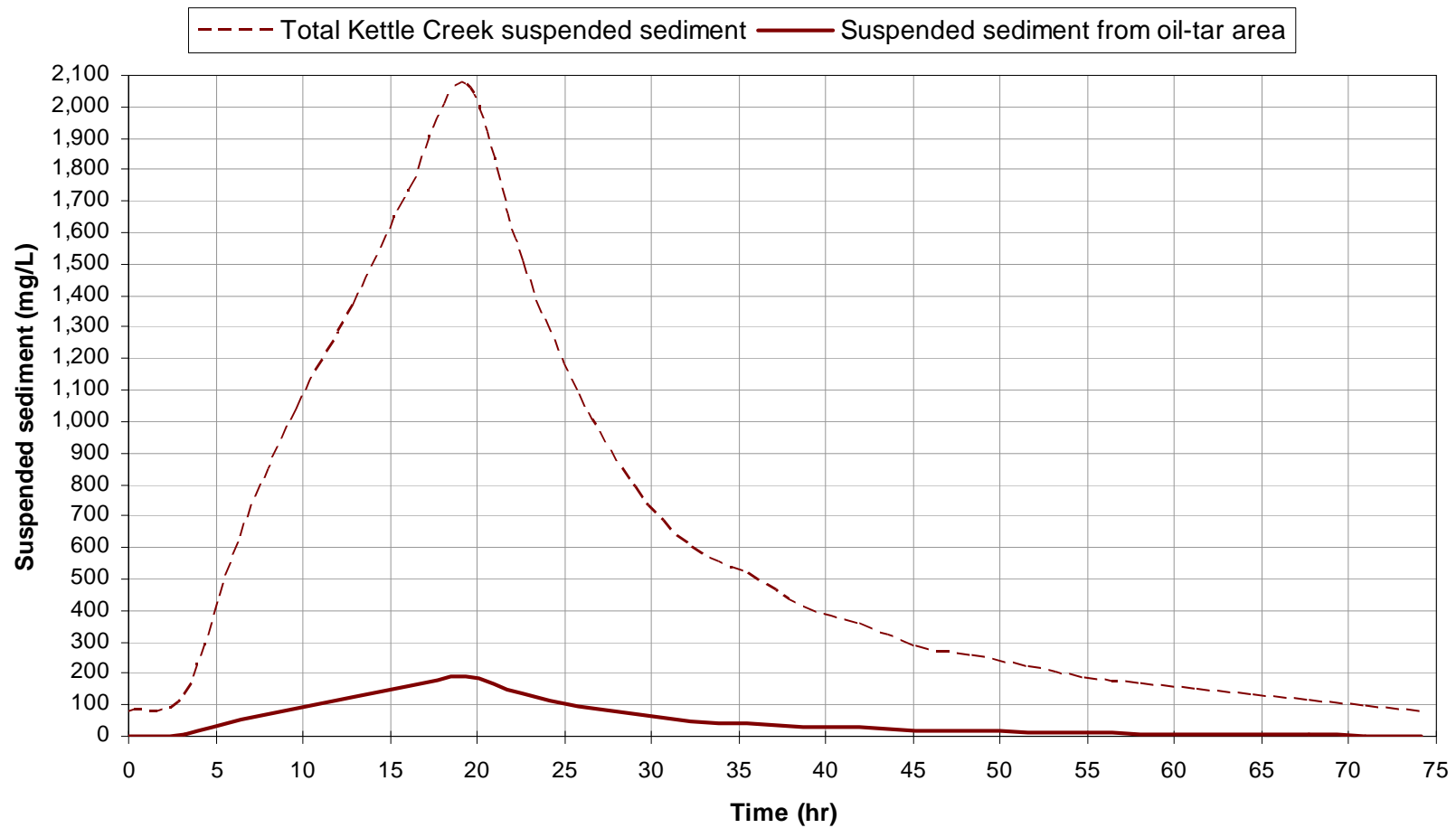


Figure 8. Total Kettle Creek and oil-tar suspended sediment for "worse-case" event

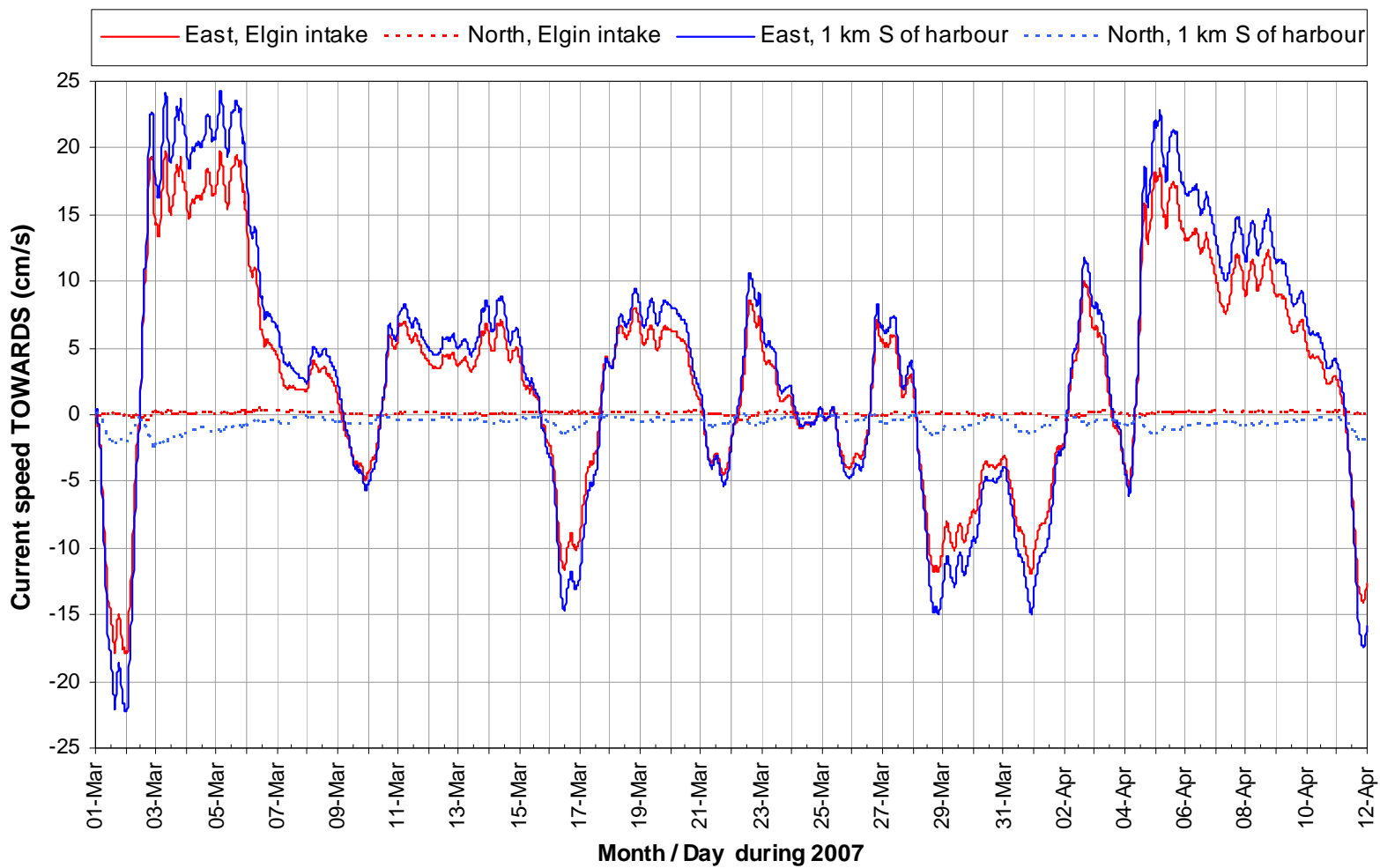


Figure 9. Water velocity in the lake - 1 March to 12 April, 2007

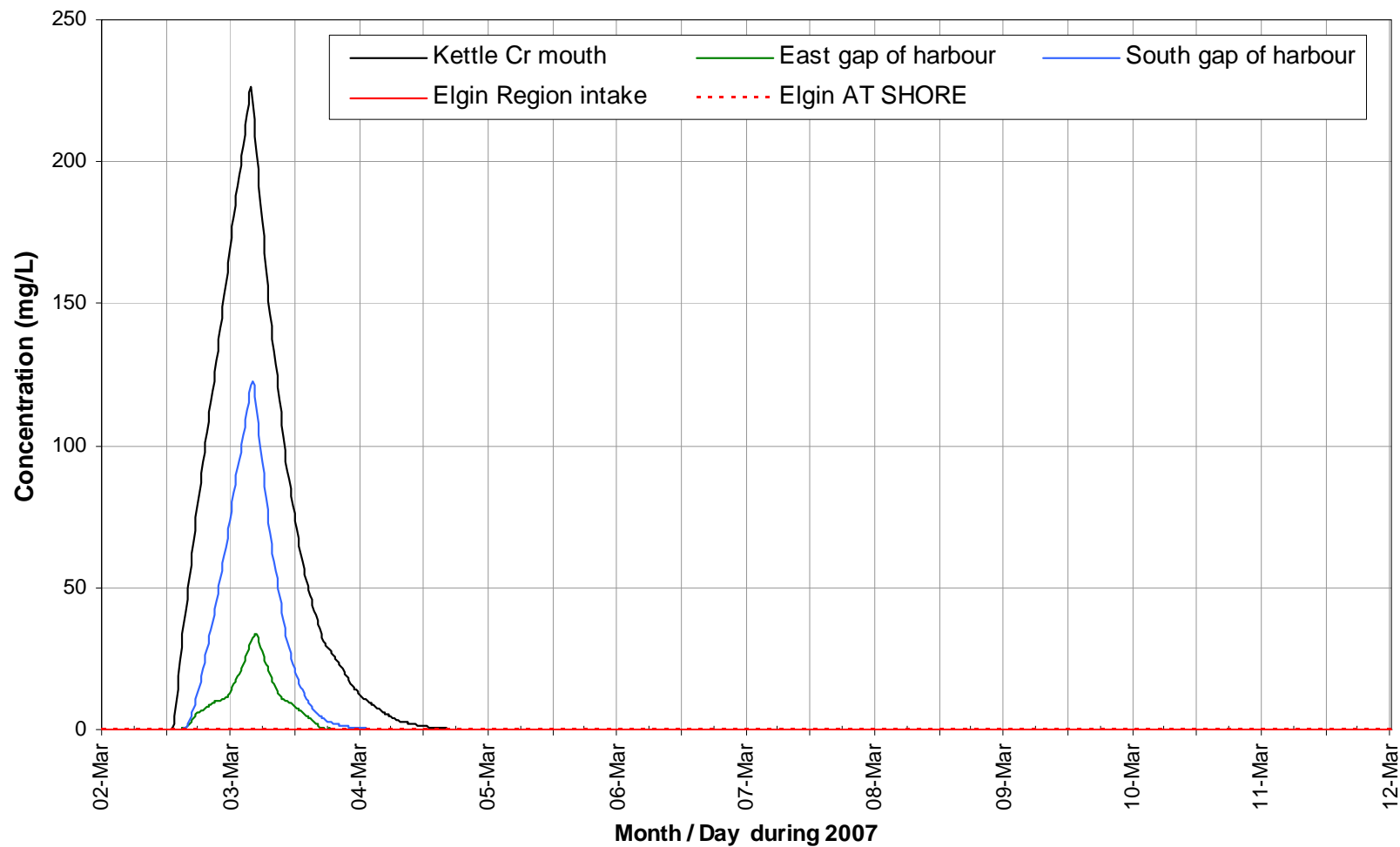


Figure 10R1. Release 1 - Concentrations of suspended solids if all FINE SAND (*the LIKELY CASE*)

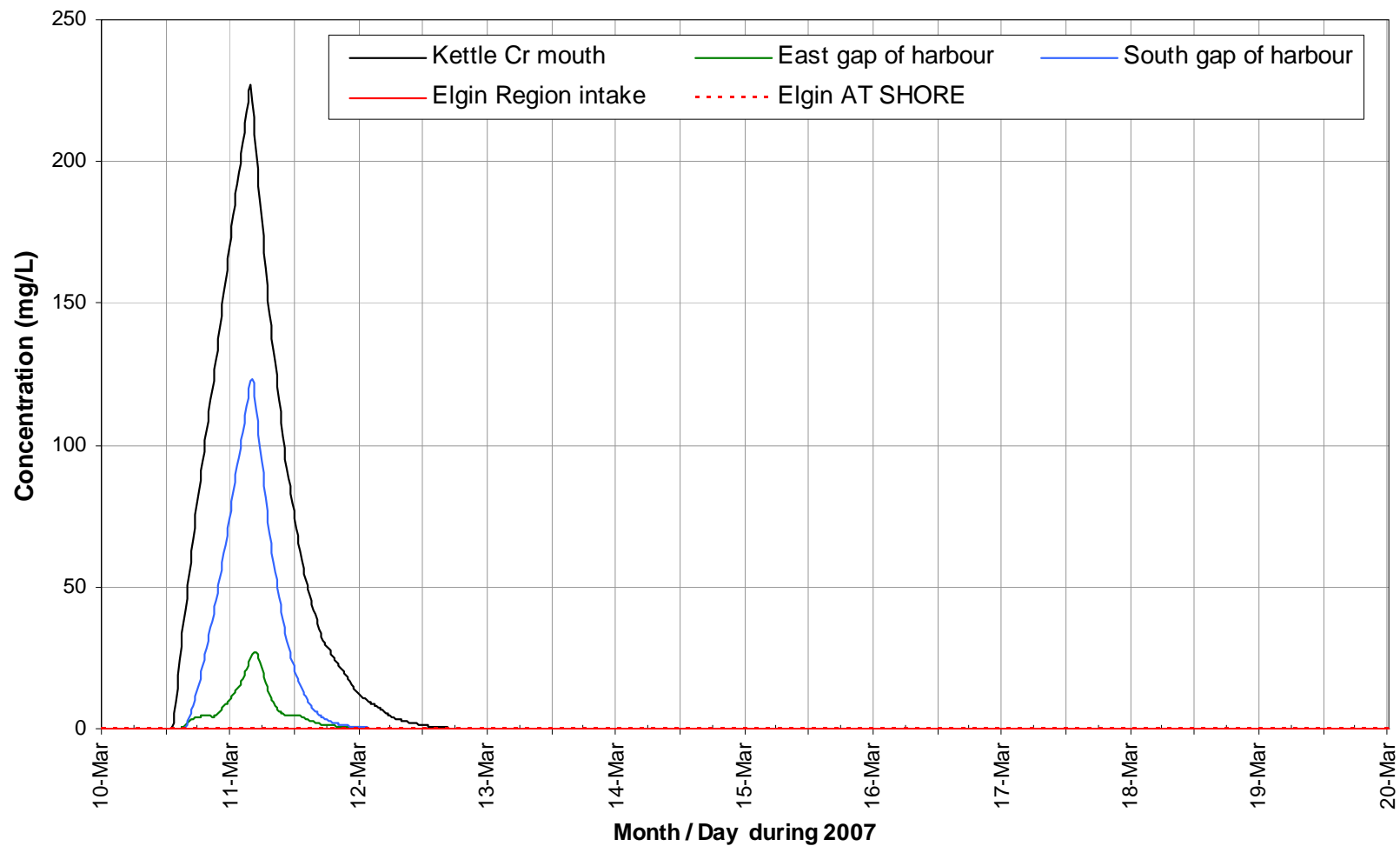


Figure 10R2. Release 2 - Concentrations of suspended solids if all FINE SAND (*the LIKELY CASE*)

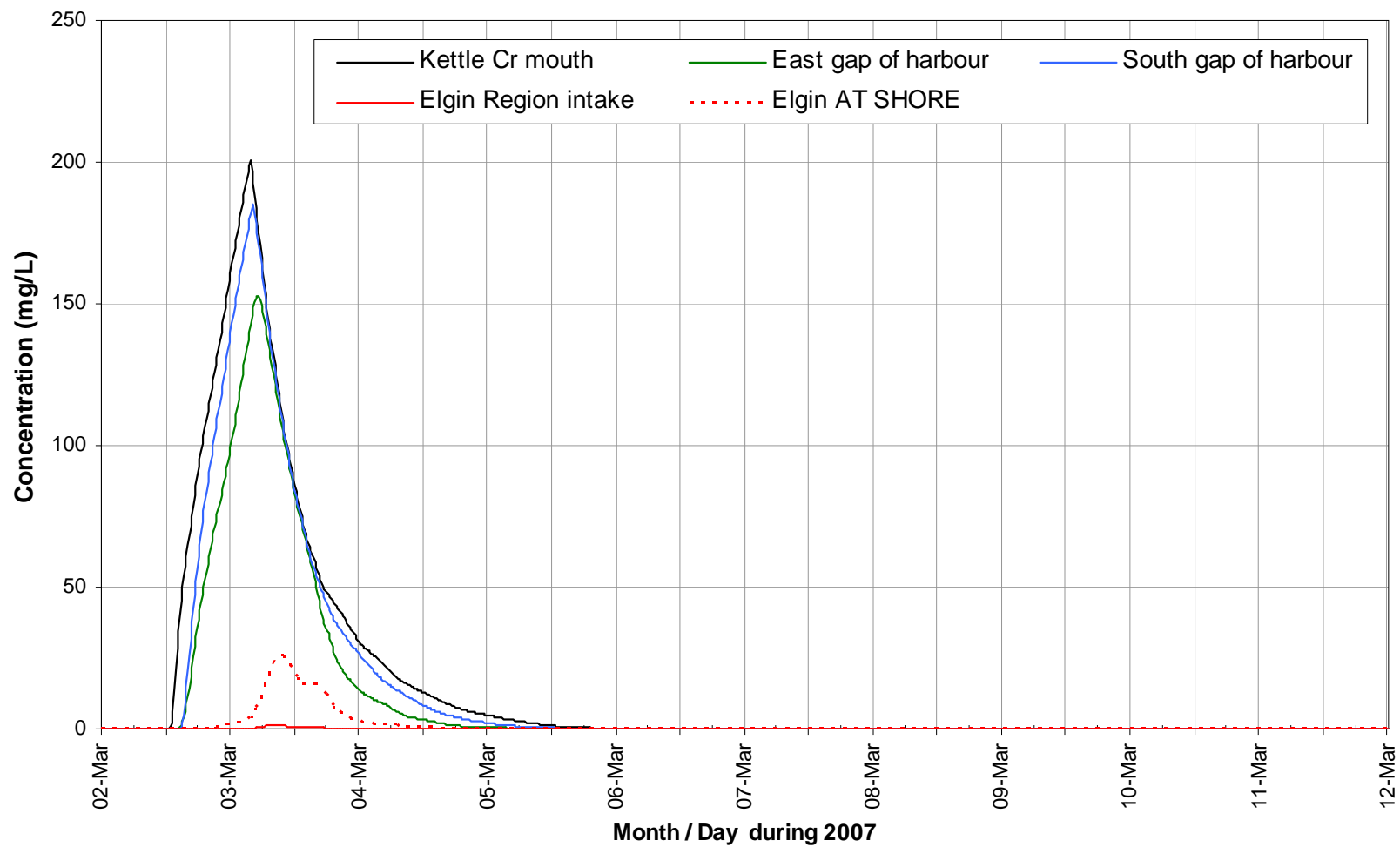


Figure 11R1. Release 1 - Concentrations of suspended solids IF all MEDIUM SILT

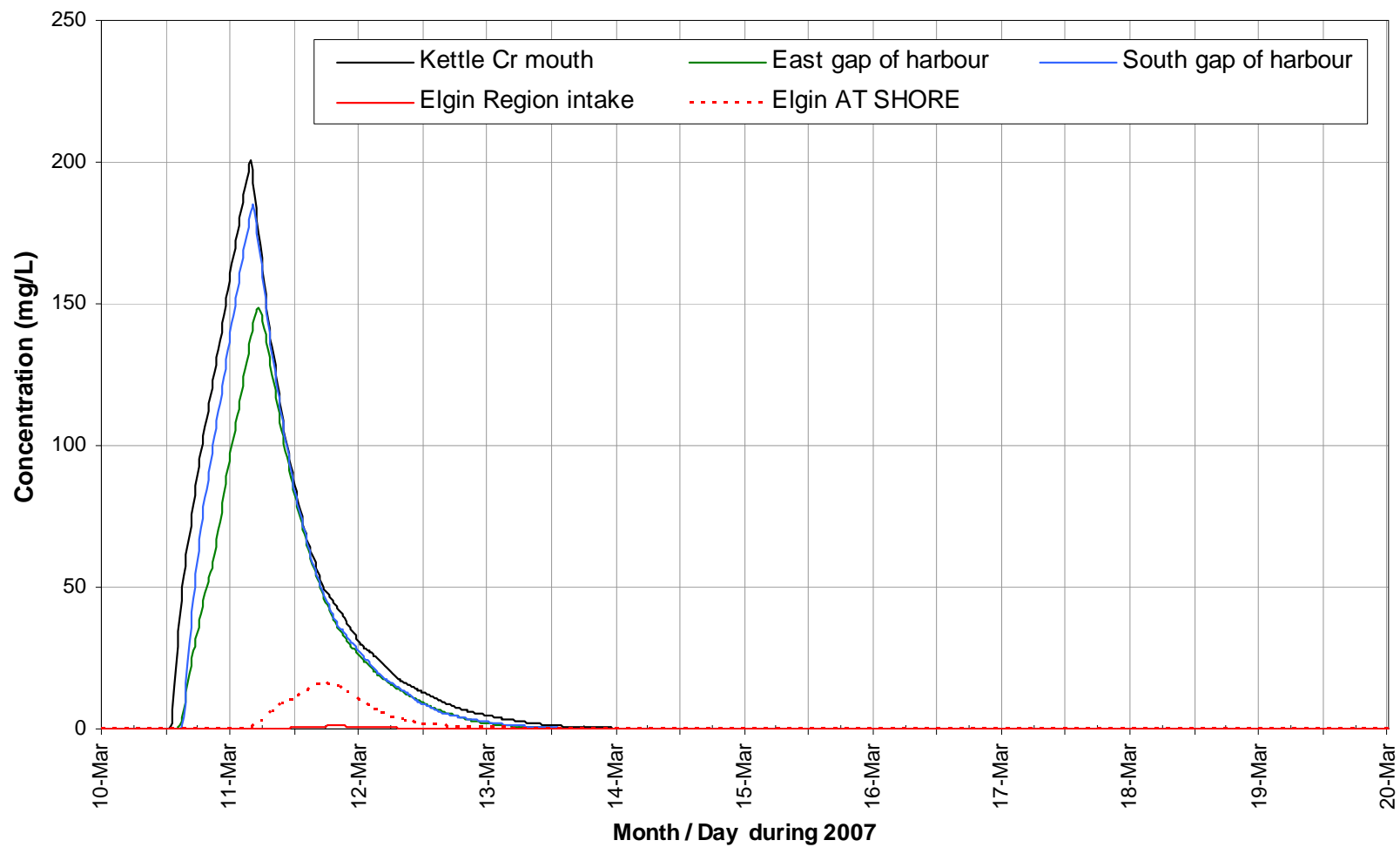


Figure 11R2. Release 2 - Concentrations of suspended solids IF all MEDIUM SILT

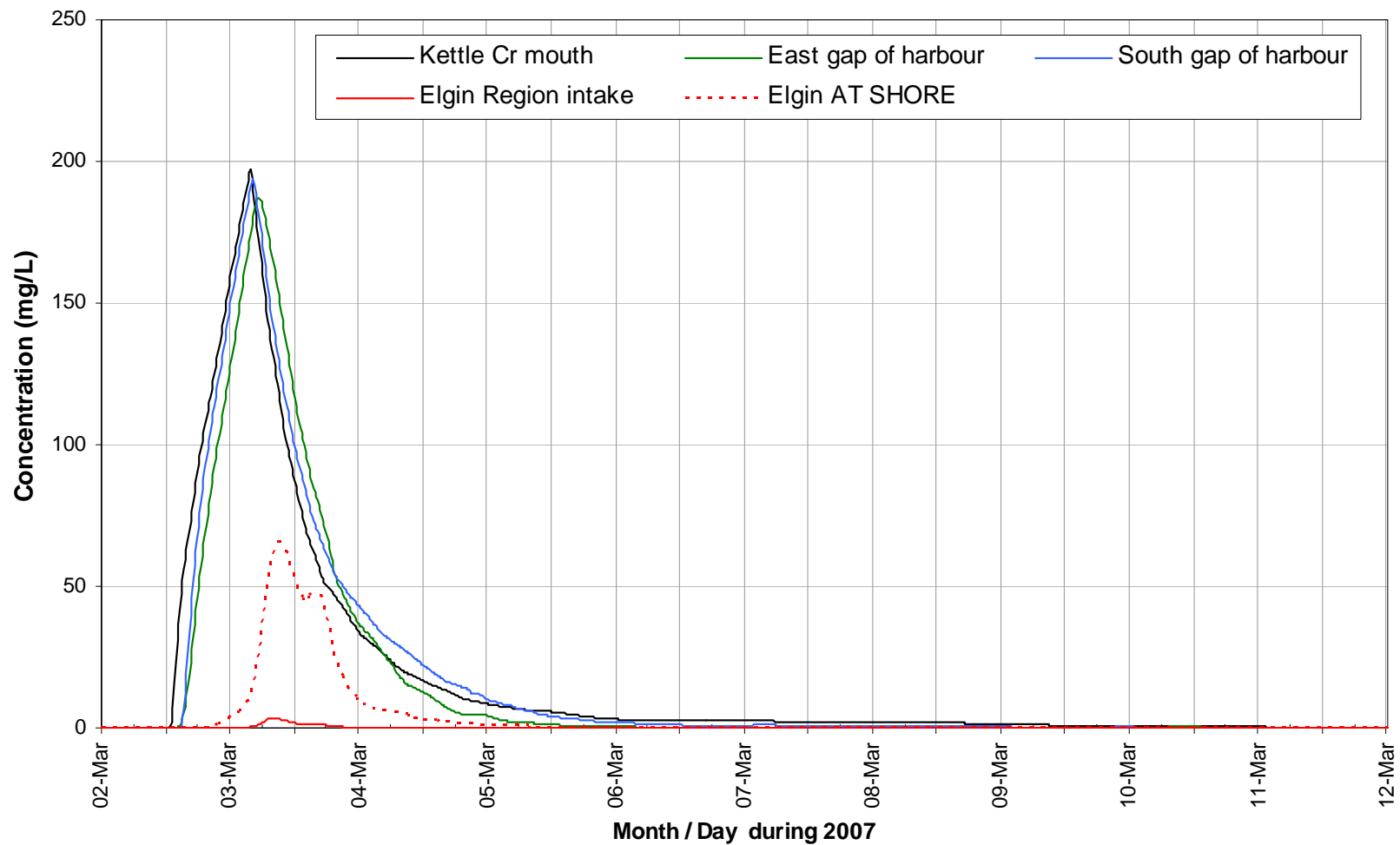


Figure 12R1. Release 1 - Concentrations of suspended solids IF all FINE SILT

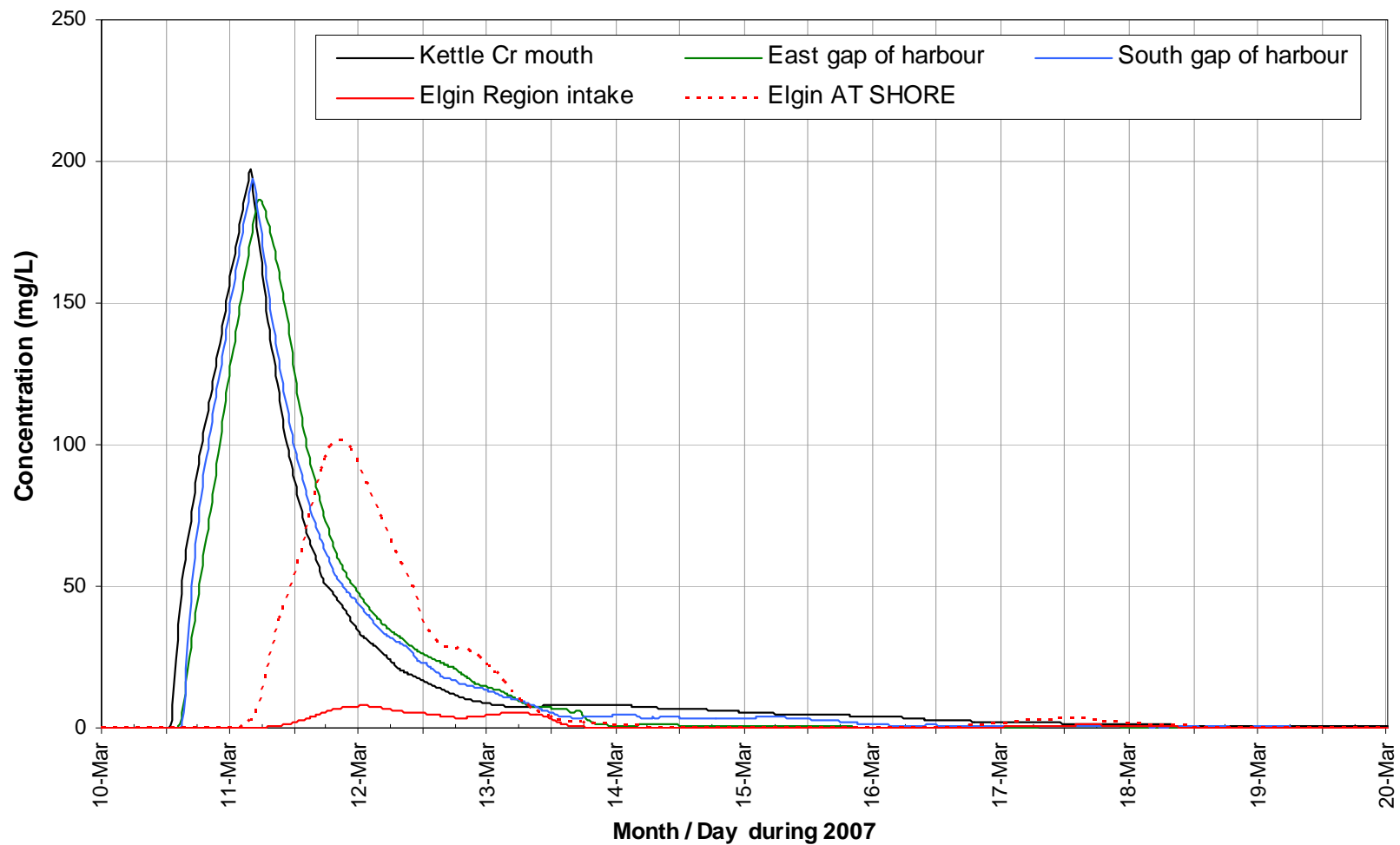


Figure 12R2. Release 2 - Concentrations of suspended solids IF all FINE SILT

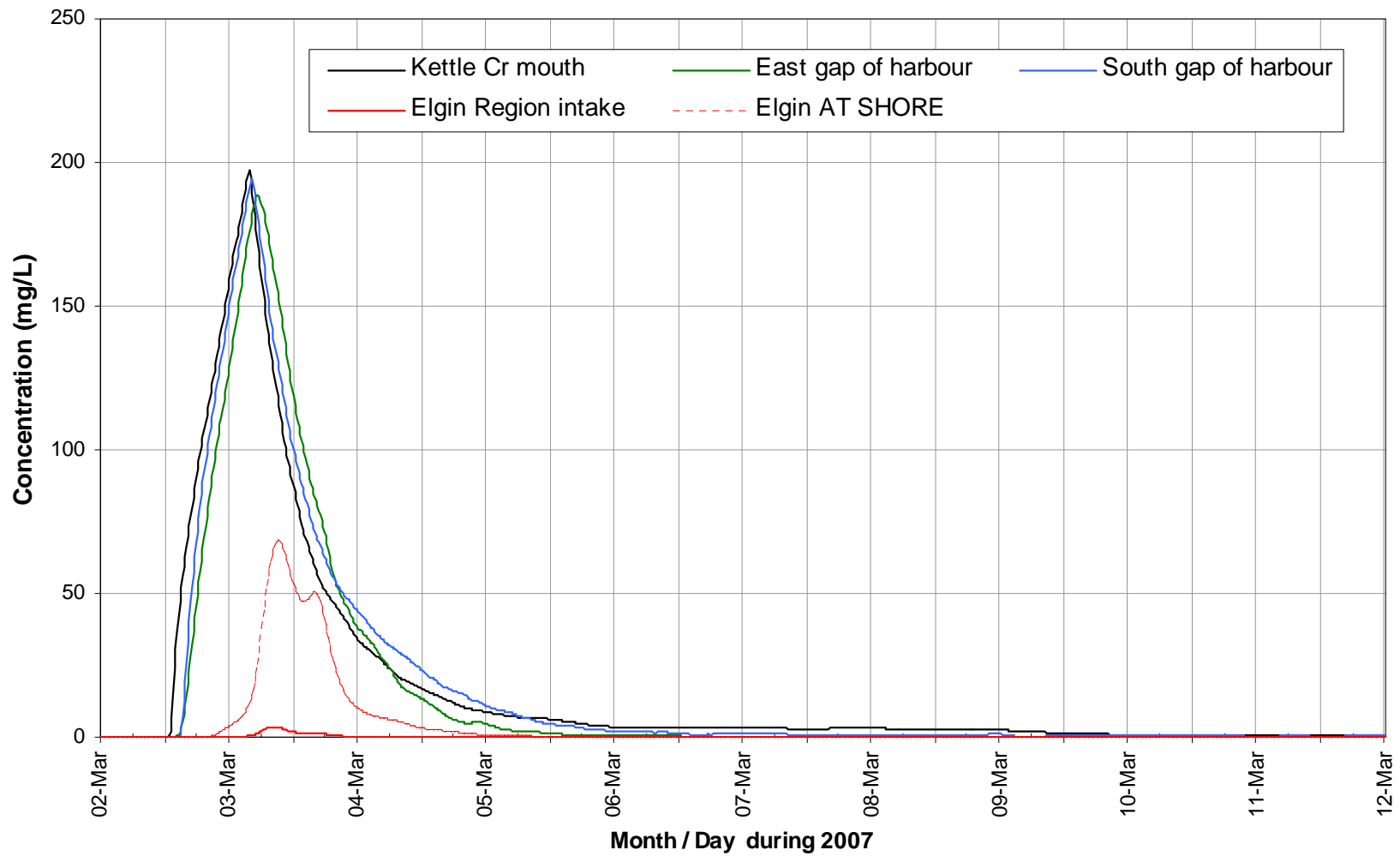


Figure 13R1. Release 1 - Conc of suspended solids with NO LOSSES from the water column

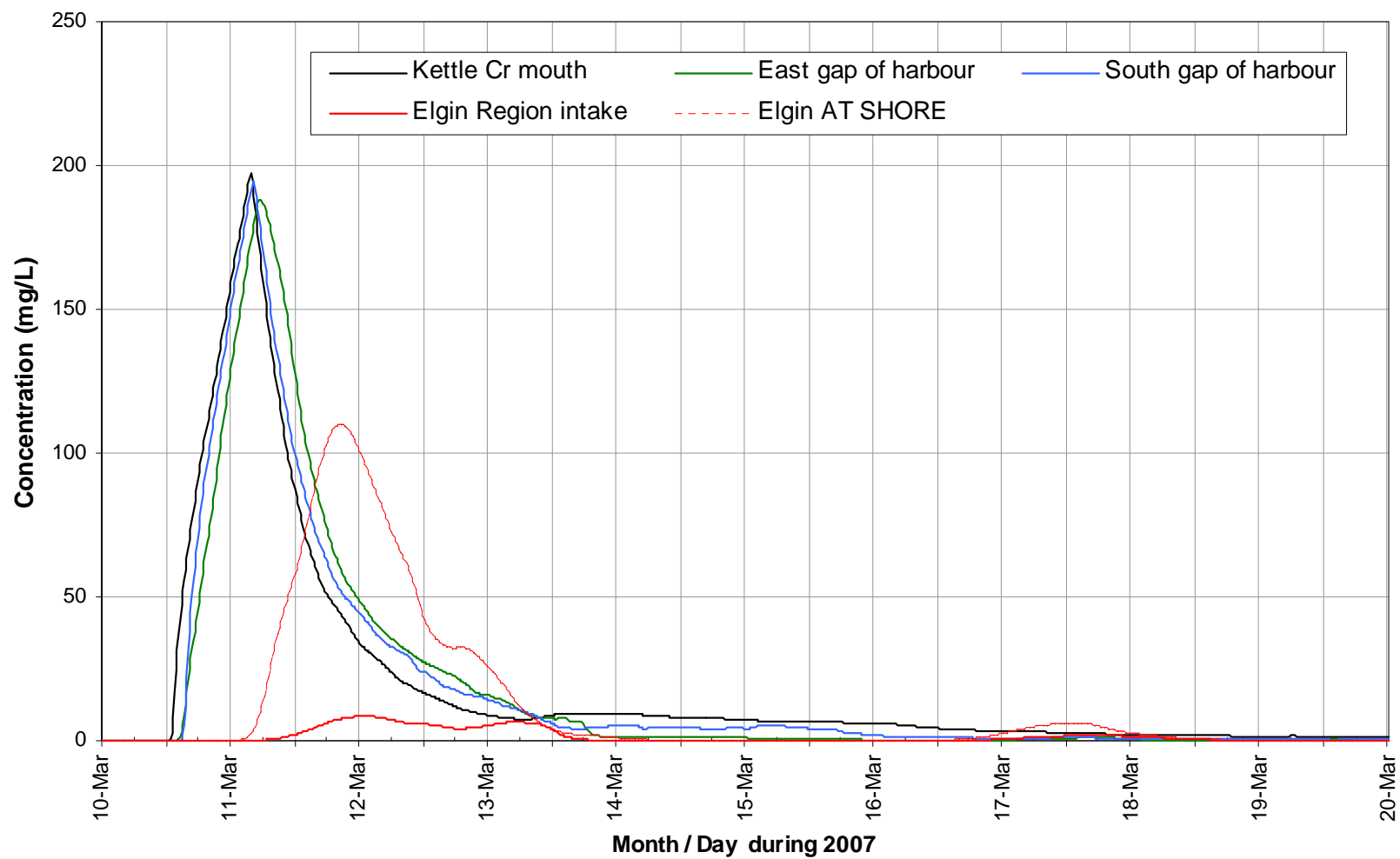


Figure 13R2. Release 2 - Conc of suspended solids with NO LOSSES from the water column

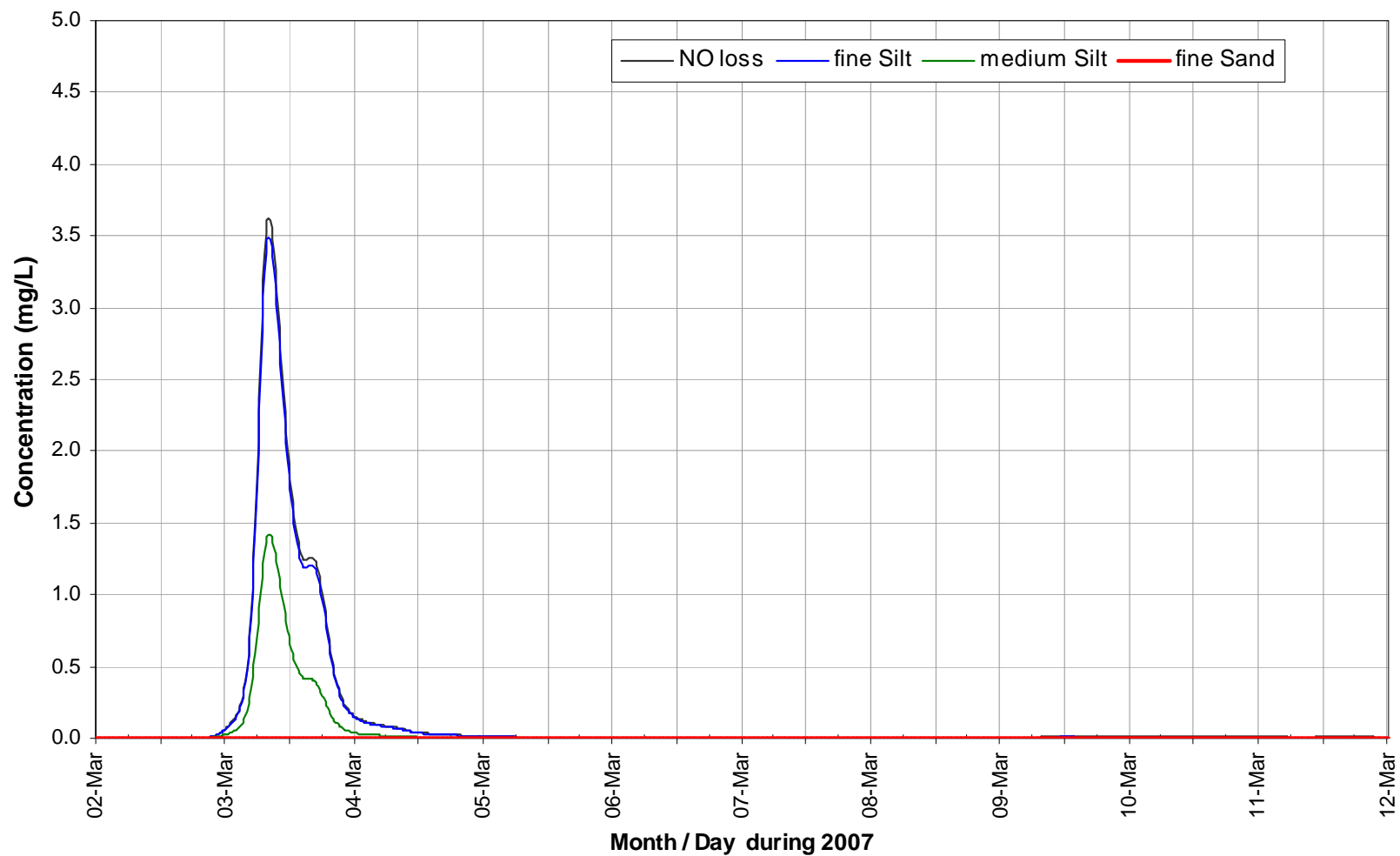


Figure 14R1. Release 1 - Suspended sediment concentration at the Elgin Region intake

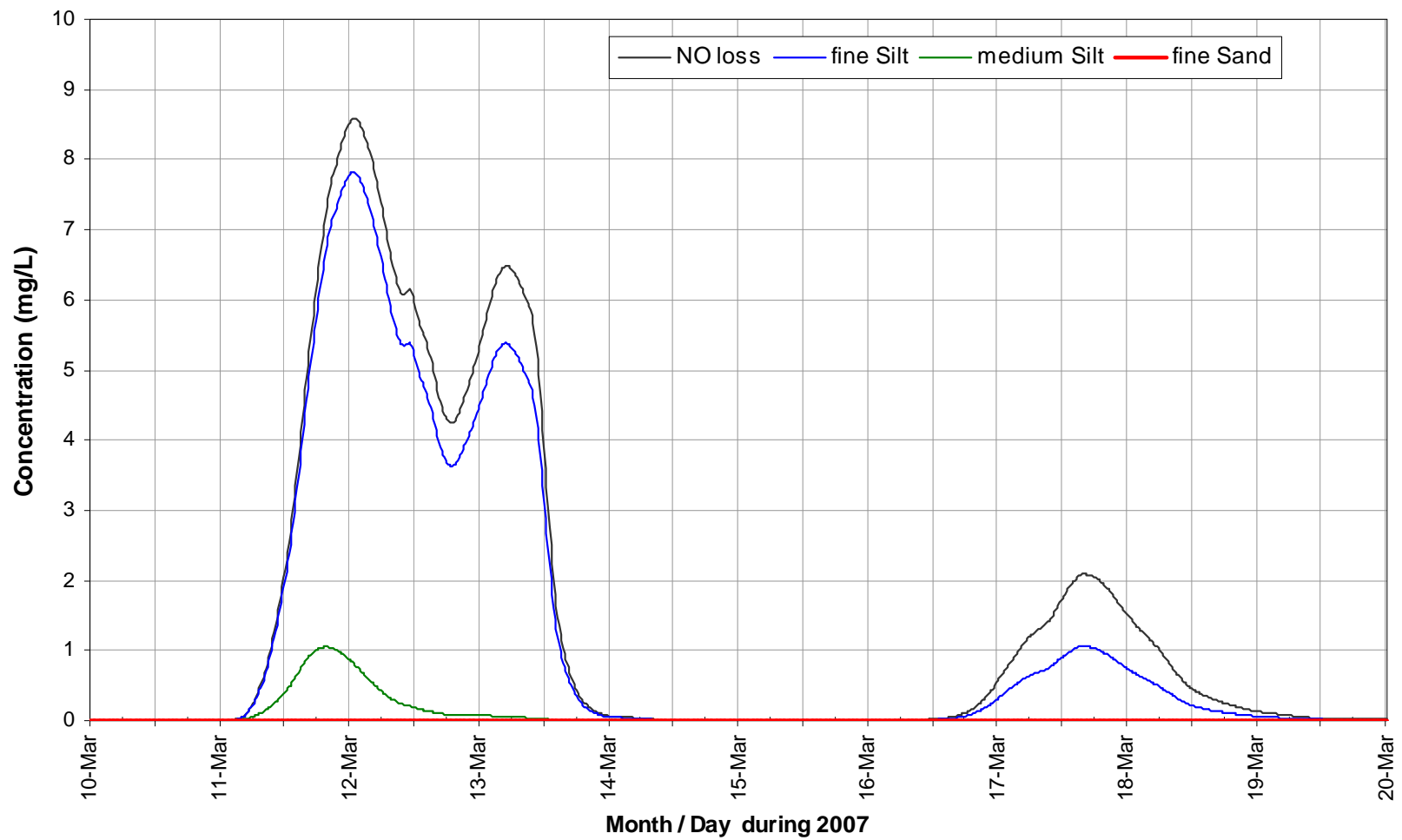


Figure 14R2. Release 2 - Suspended sediment concentration at the Elgin Region intake

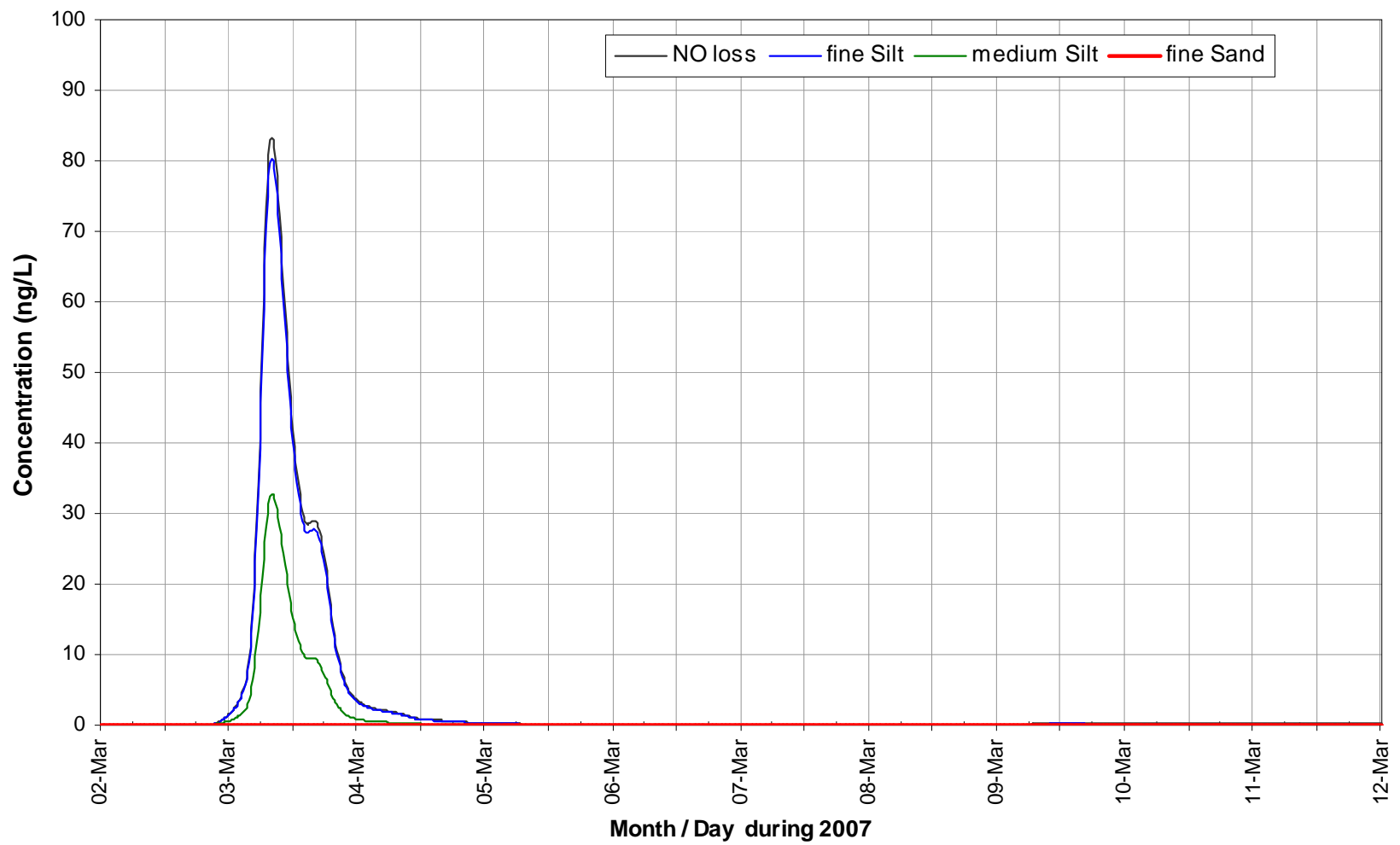


Figure 15R1. Release 1 - PAH concentration (ppb in whole-water) at the Elgin Region intake

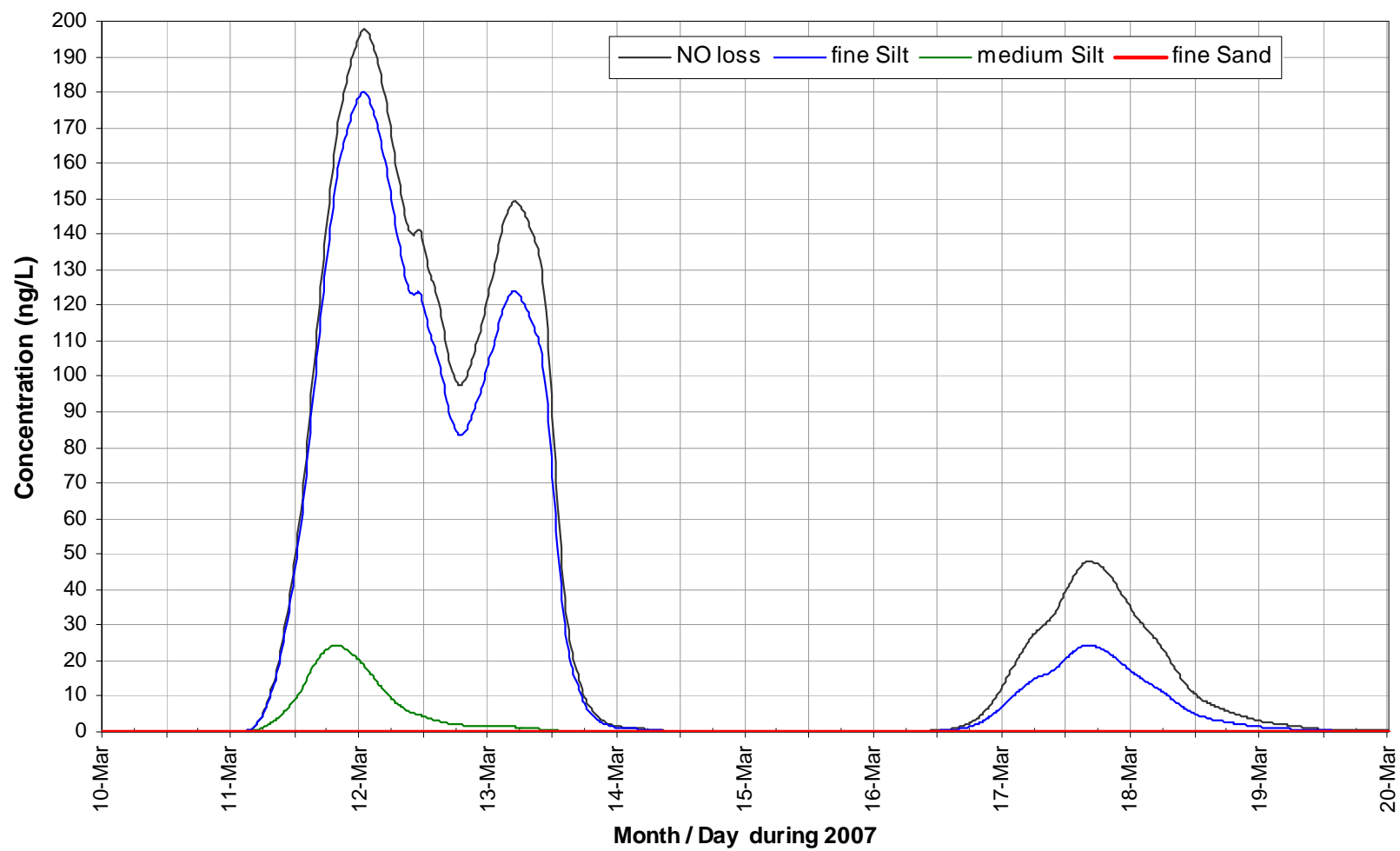
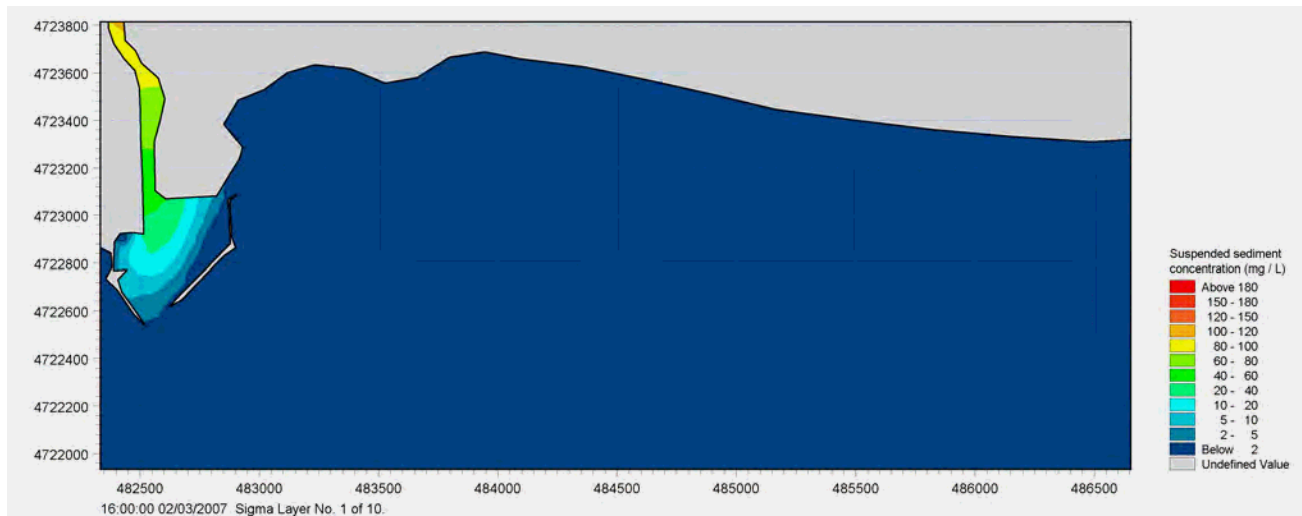
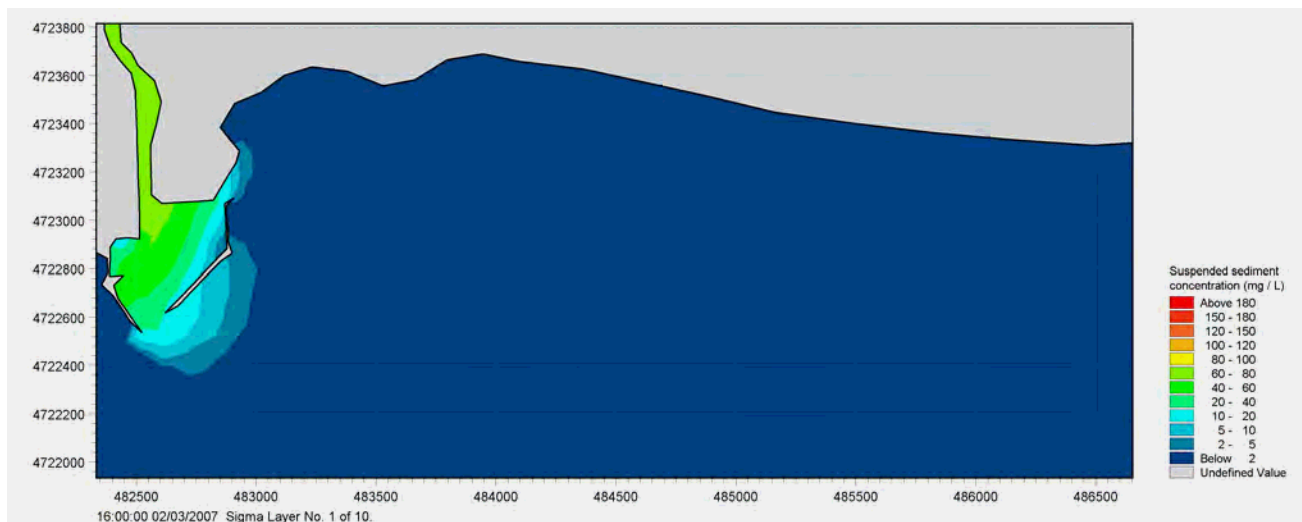


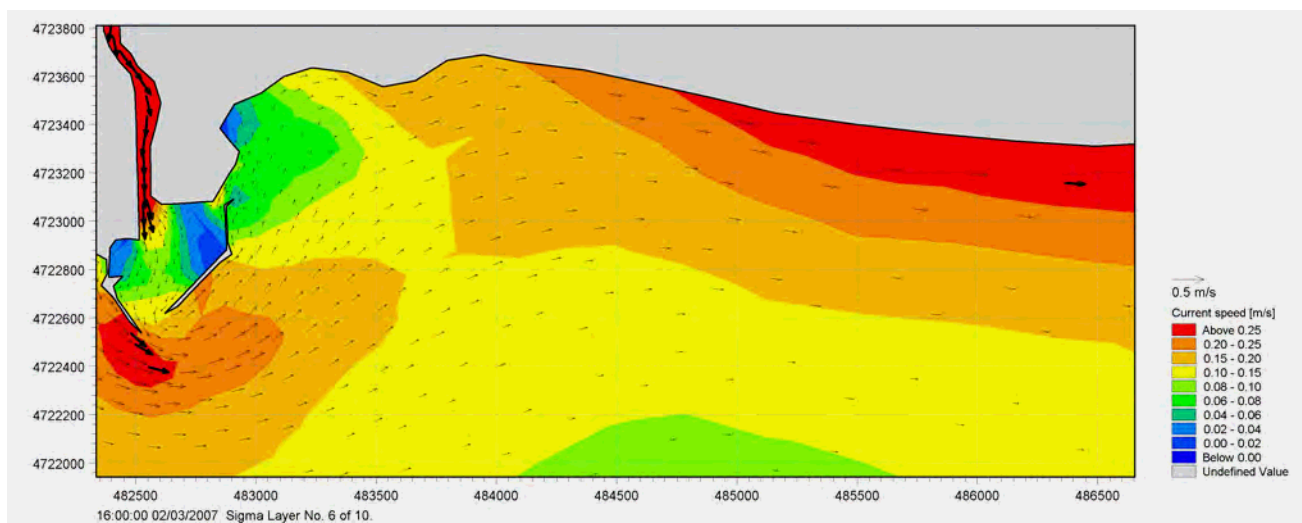
Figure 15R2. Release 2 - PAH concentration (ppb in whole-water) at the Elgin Region intake



(a)

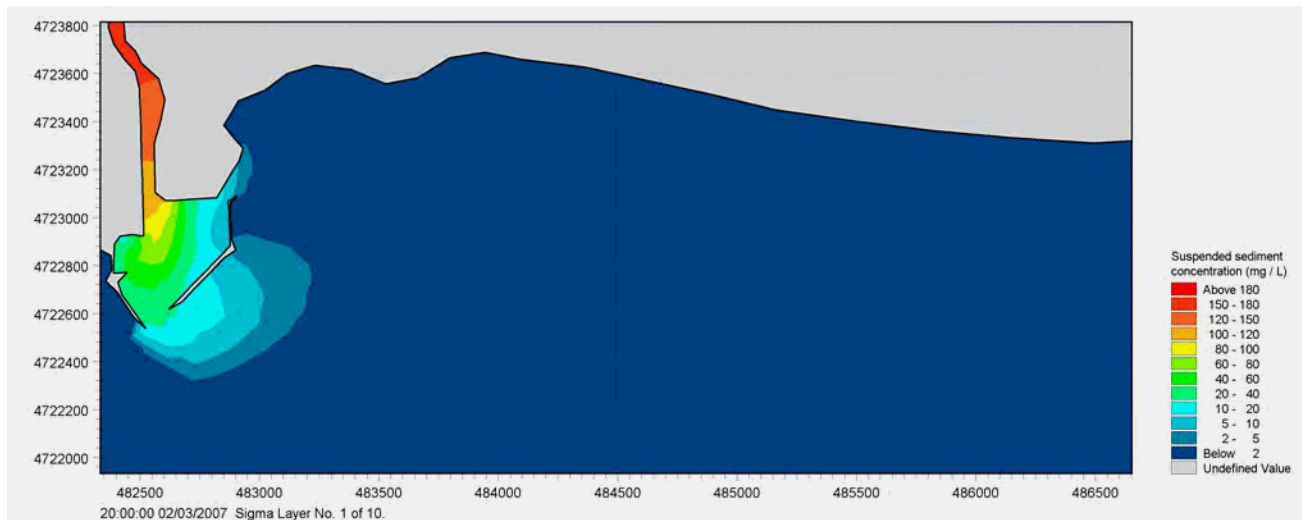


(b)

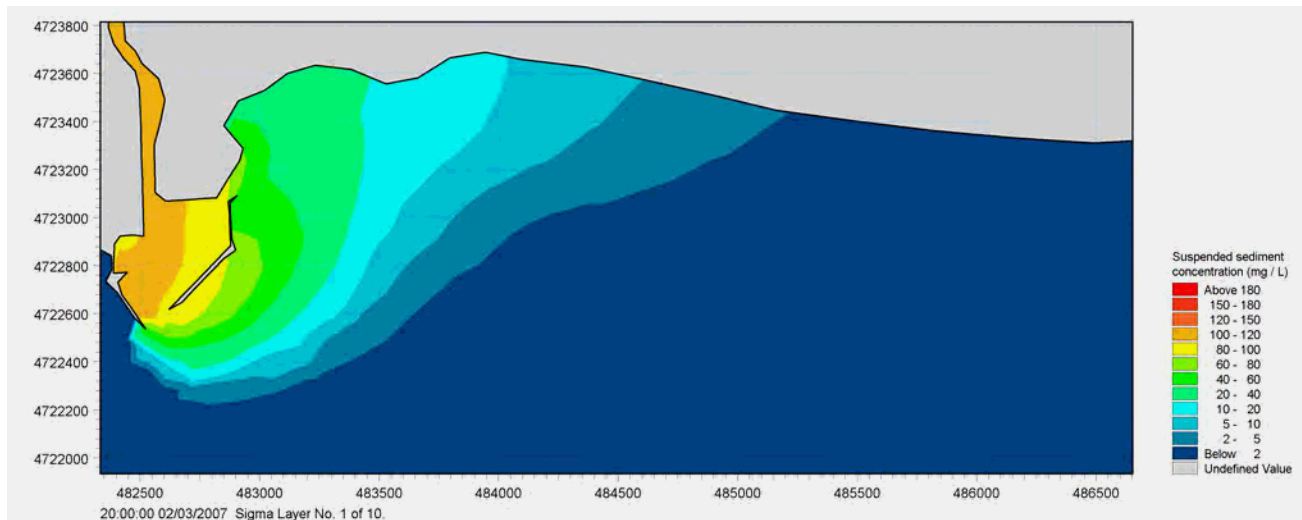


(c)

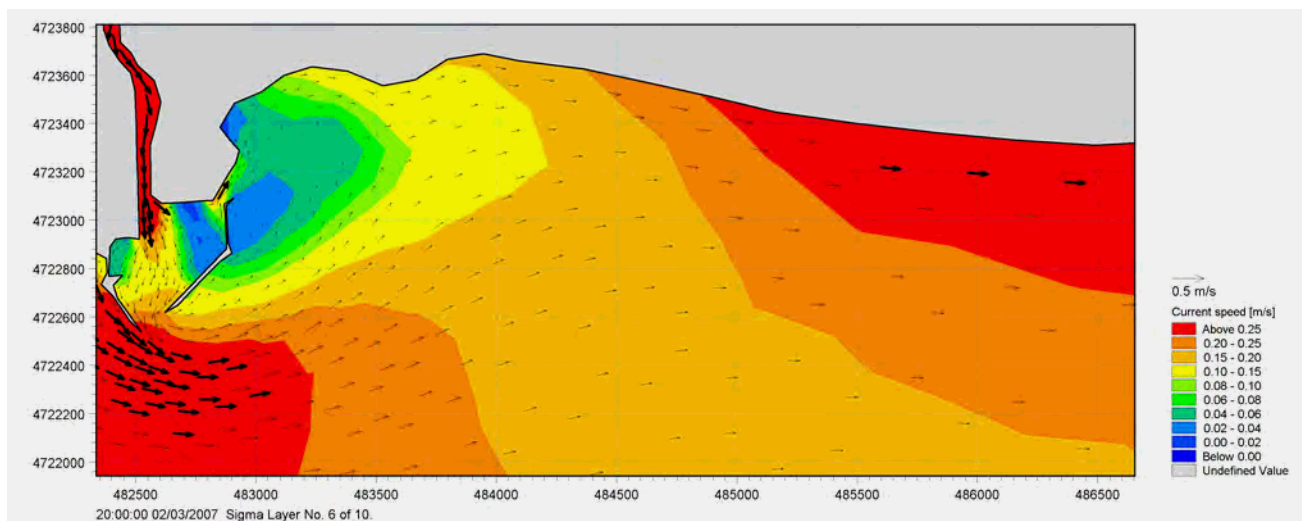
Figure 16a. Release 1 ; Snapshot 1 @ [peak plume time at Kettle Creek – 12 hrs], (2 March 16:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

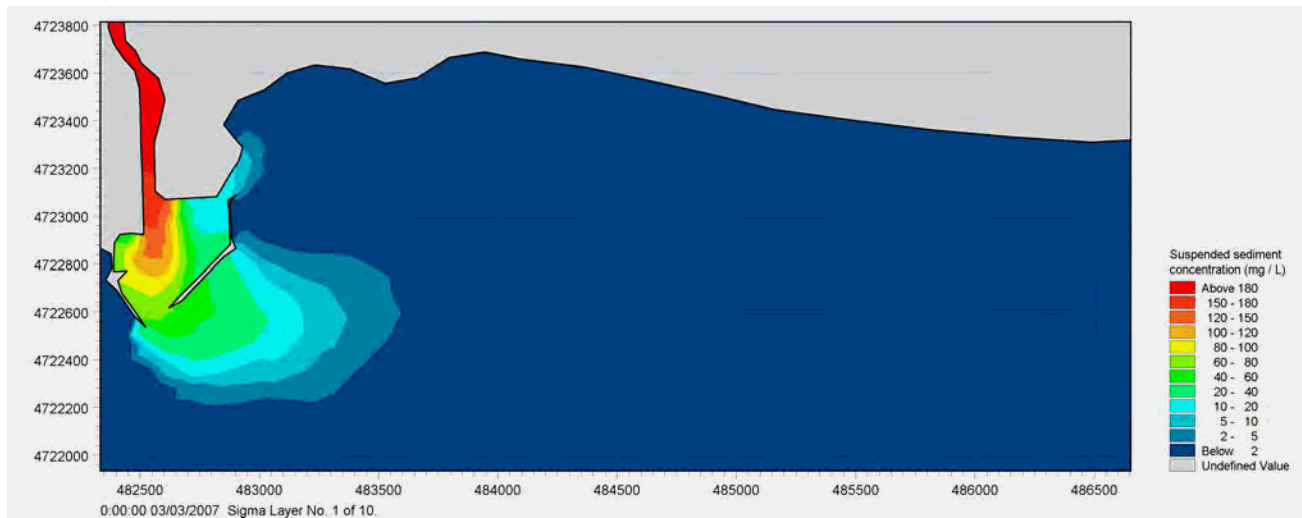


(b)

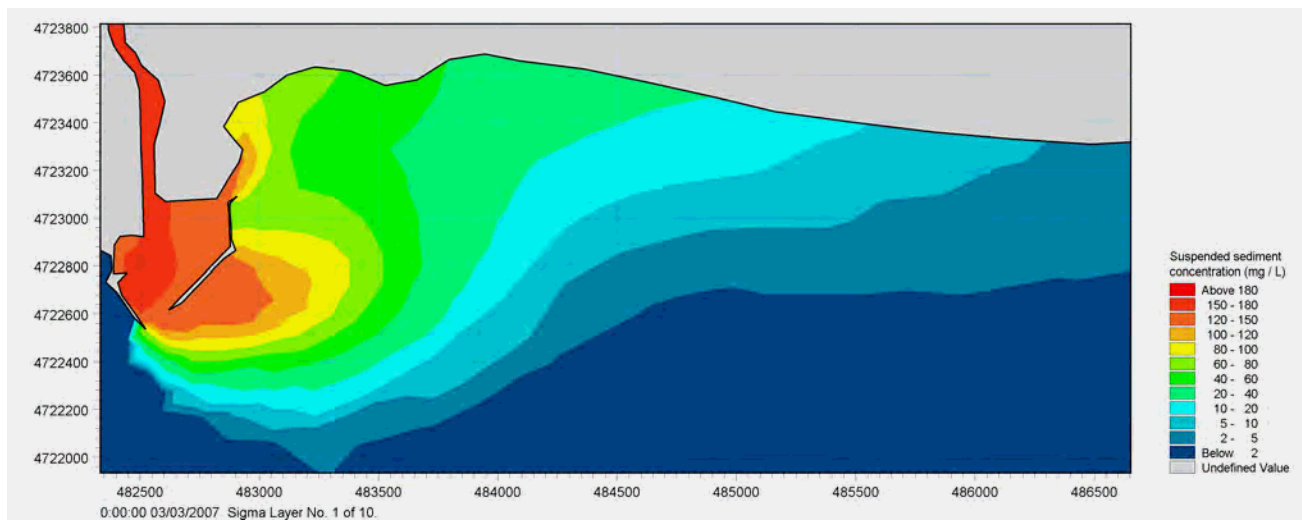


(c)

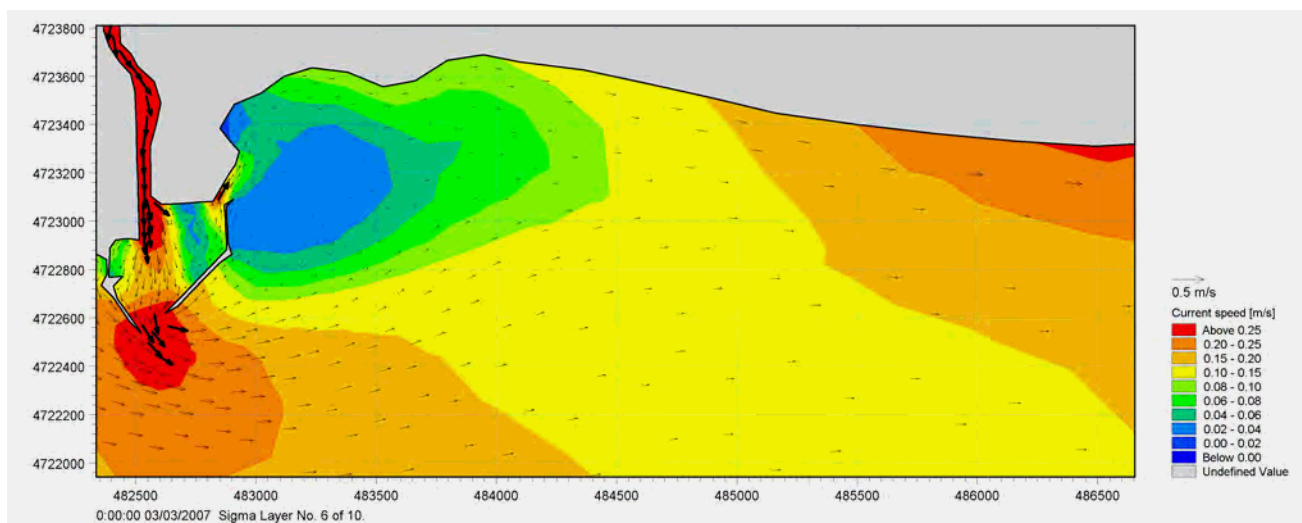
Figure 16b. Release 1 ; Snapshot 2 @ [peak plume time at Kettle Creek – 8 hrs], (2 March 20:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

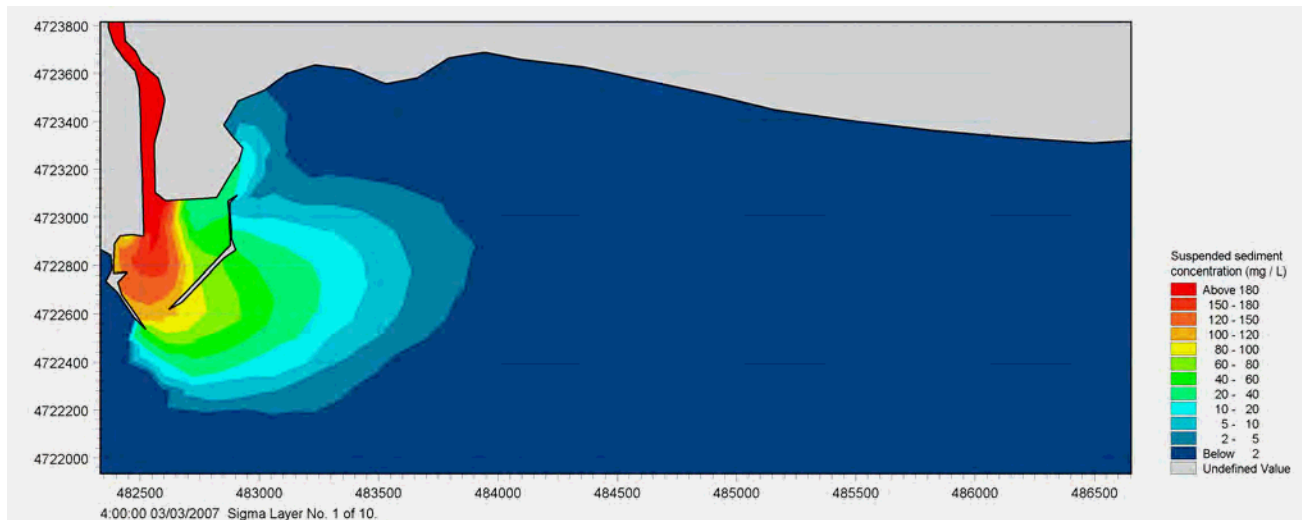


(b)

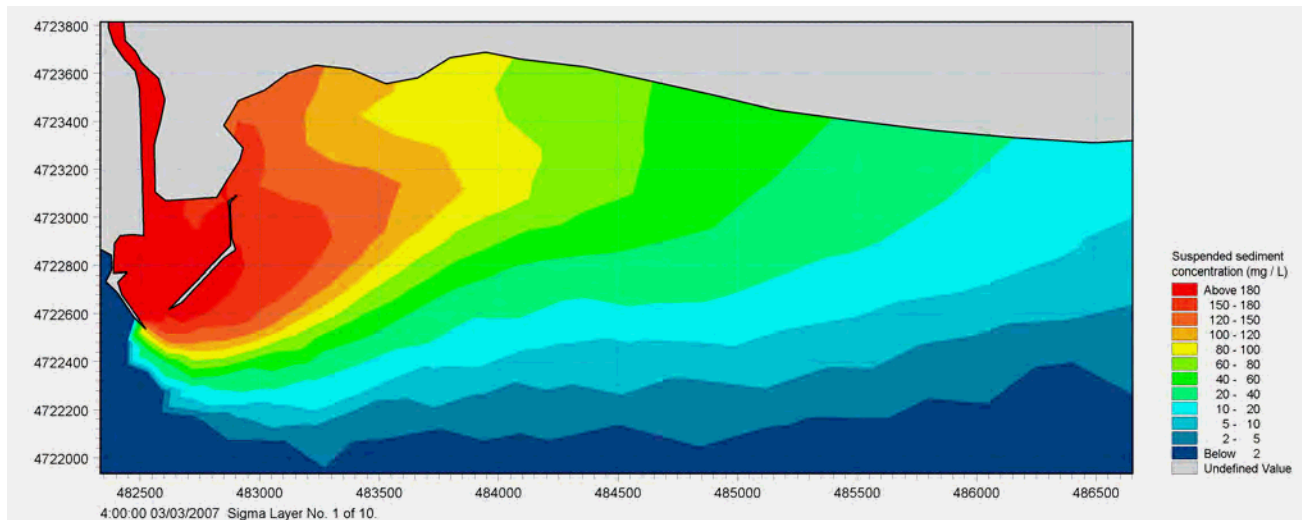


(c)

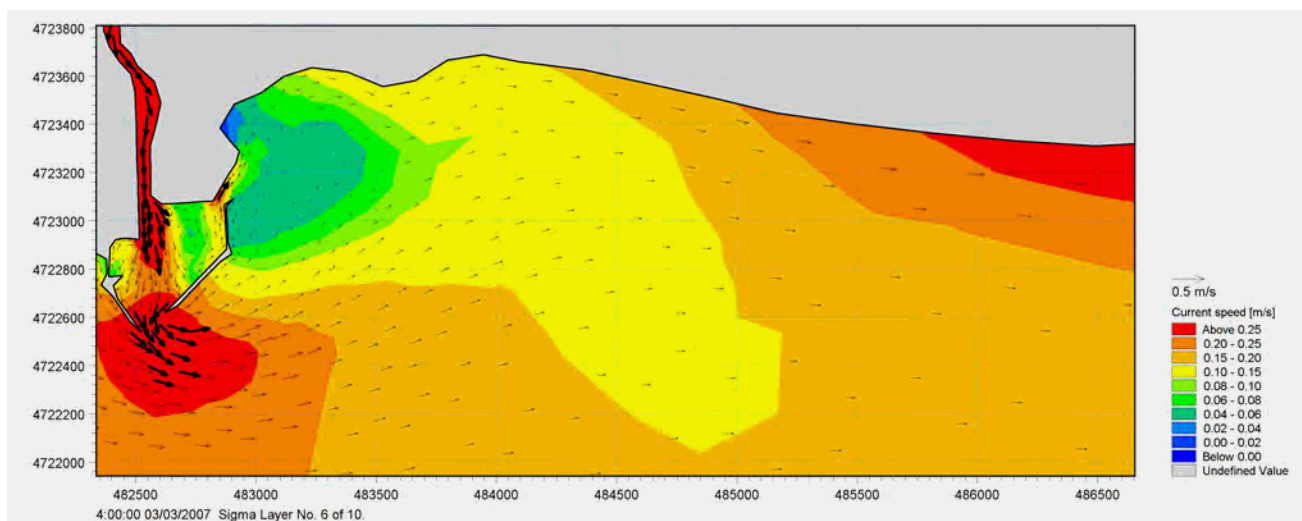
Figure 16c. Release 1 ; Snapshot 3 @ [peak plume time at Kettle Creek – 4 hrs], (3 March 00:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

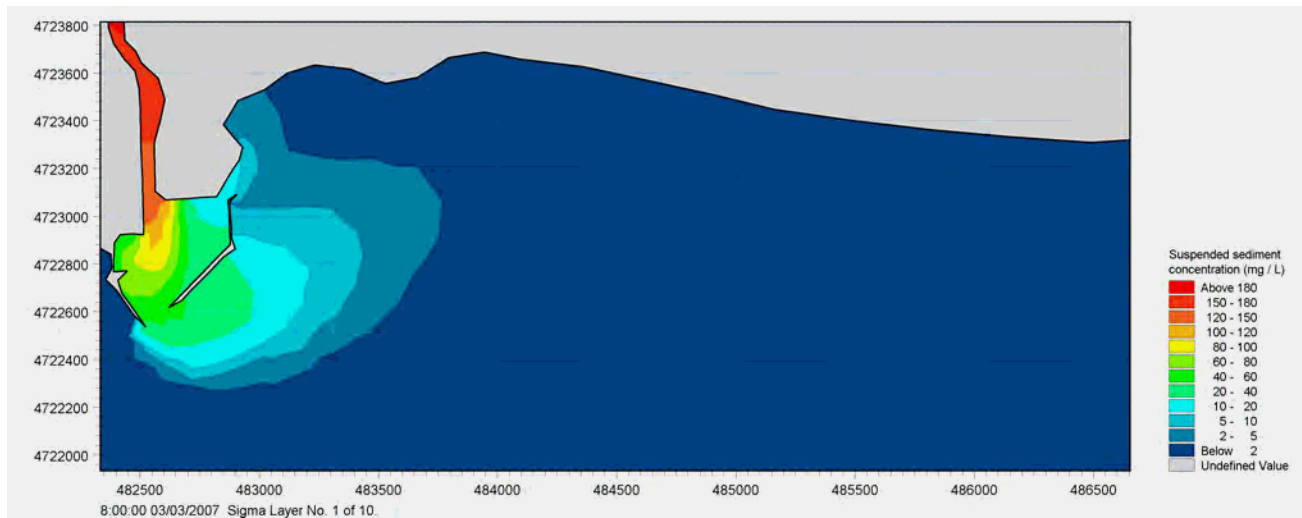


(b)

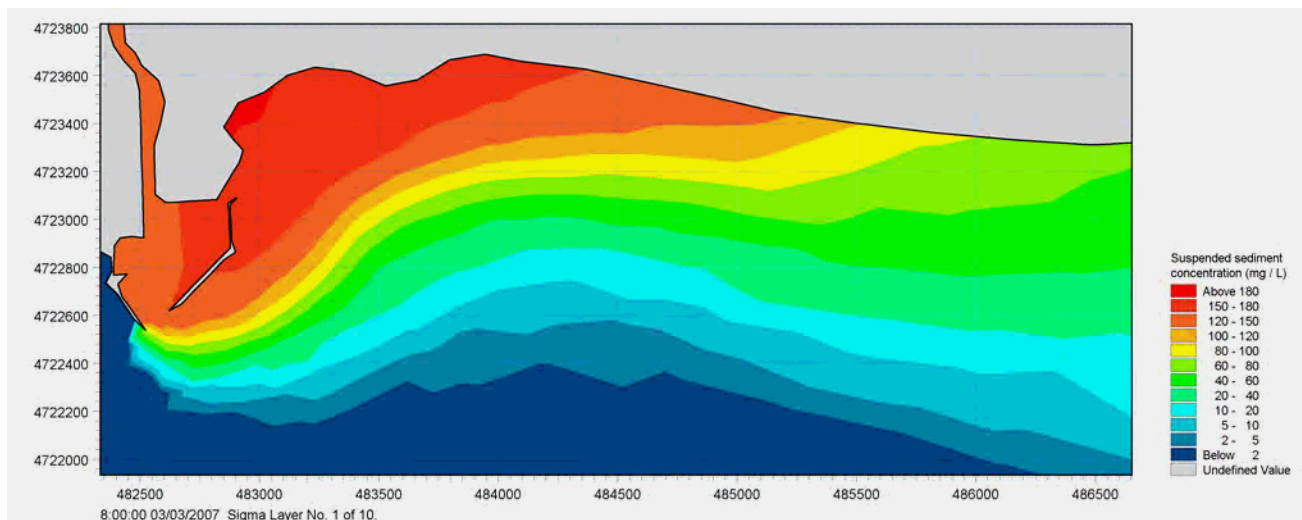


(c)

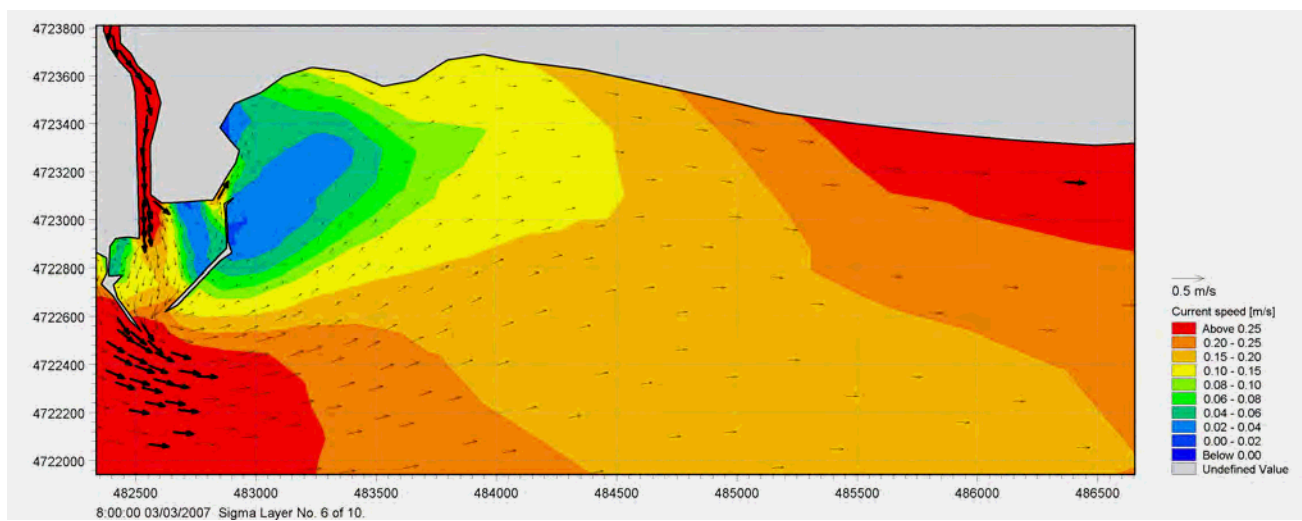
Figure 16d. Release 1 ; Snapshot 4 @ [peak plume time at Kettle Creek], (3 March 04:00).
Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

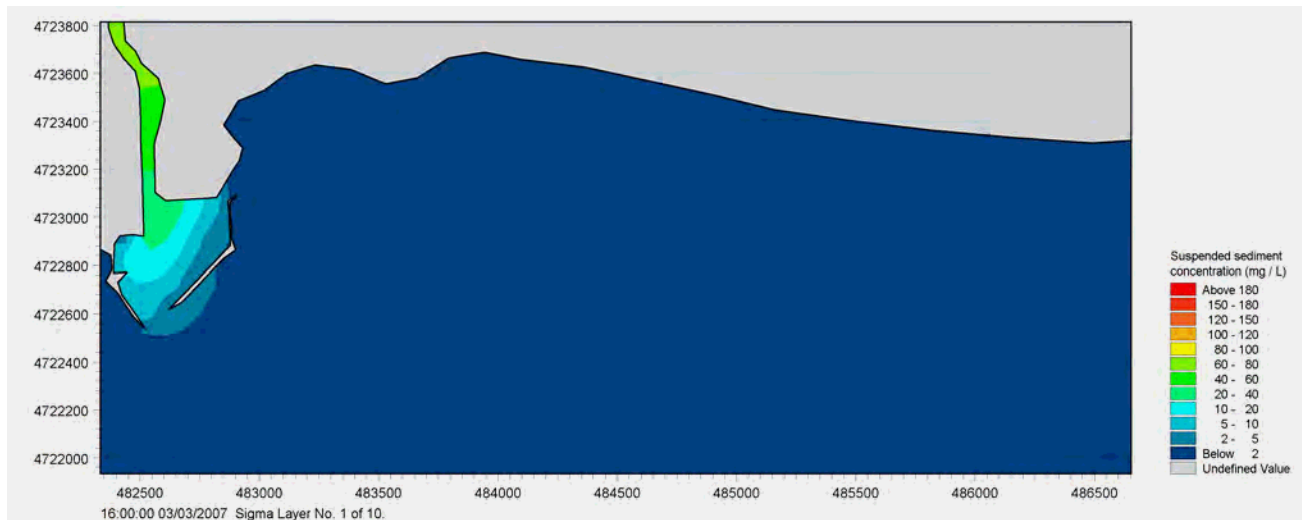


(b)

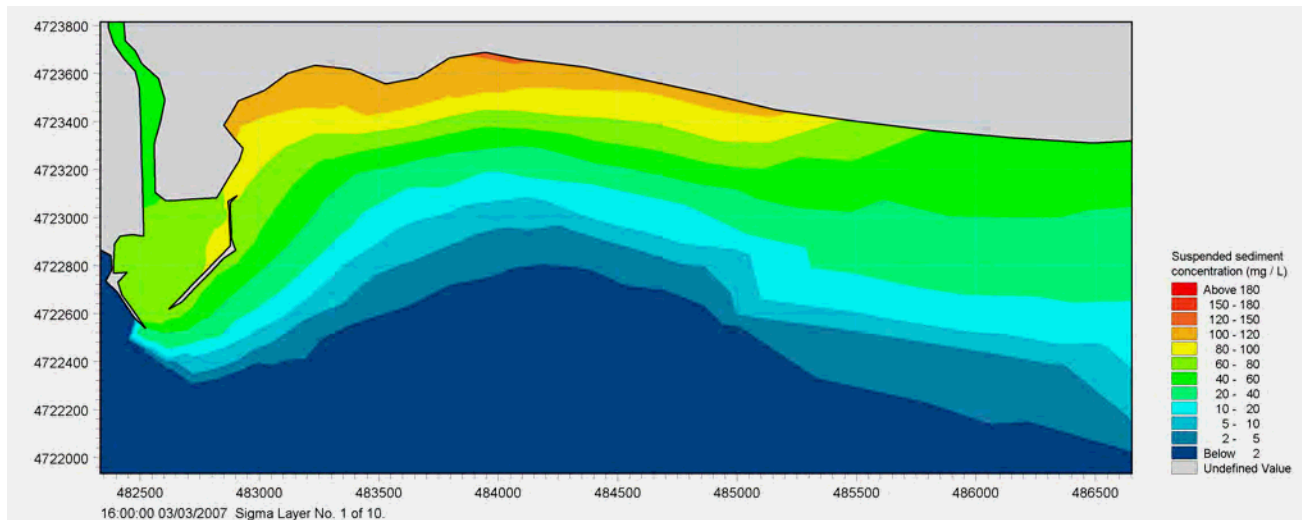


(c)

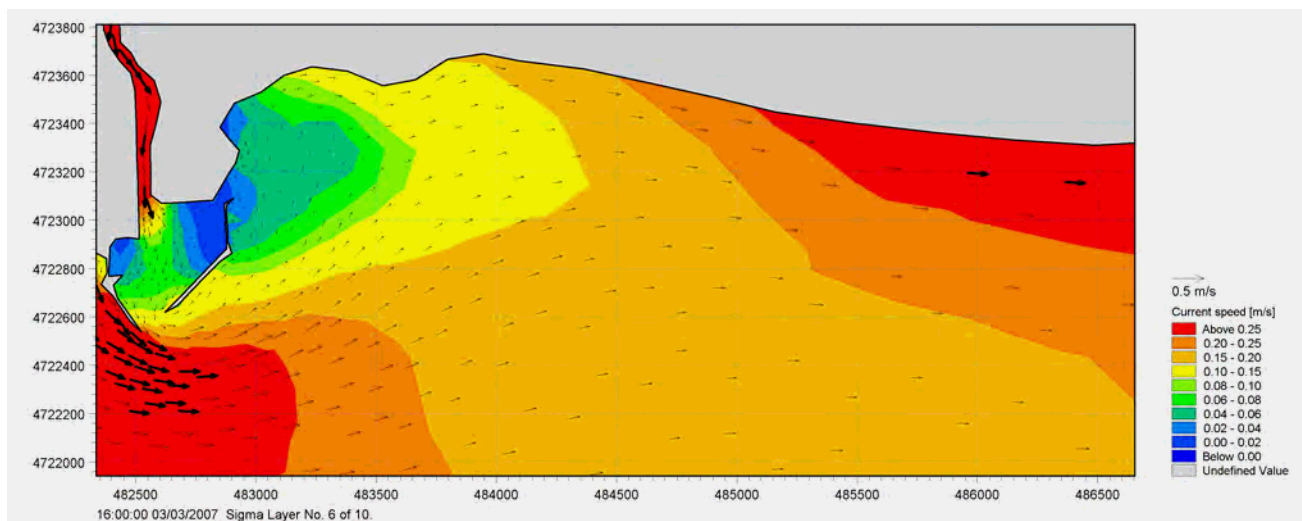
Figure 16e. Release 1 ; Snapshot 5 @ [peak plume time at Kettle Creek + 4 hrs], (3 March 08:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

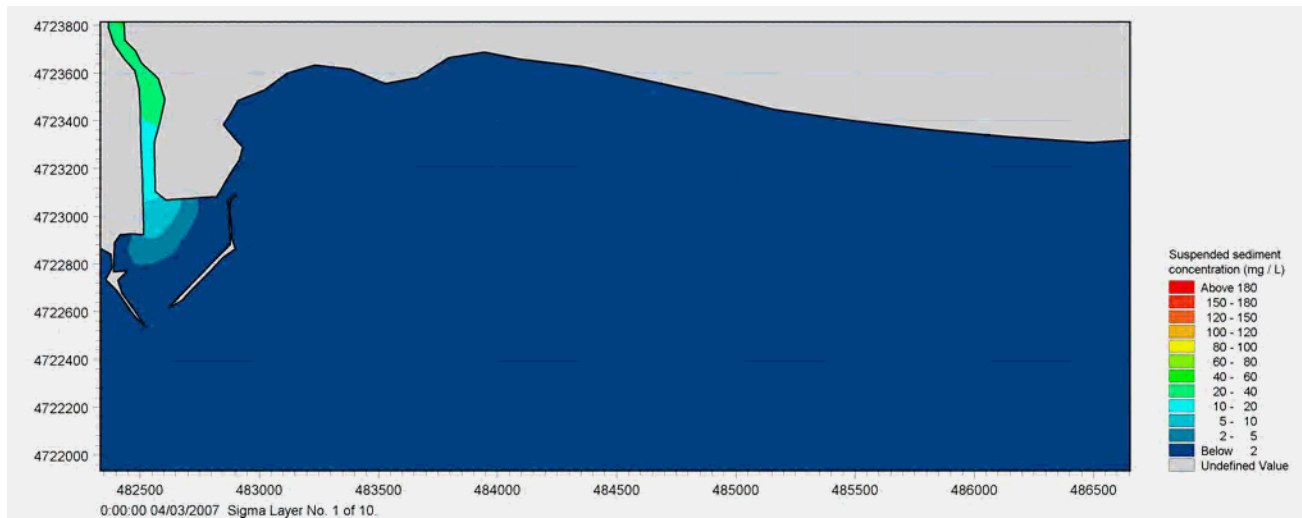


(b)

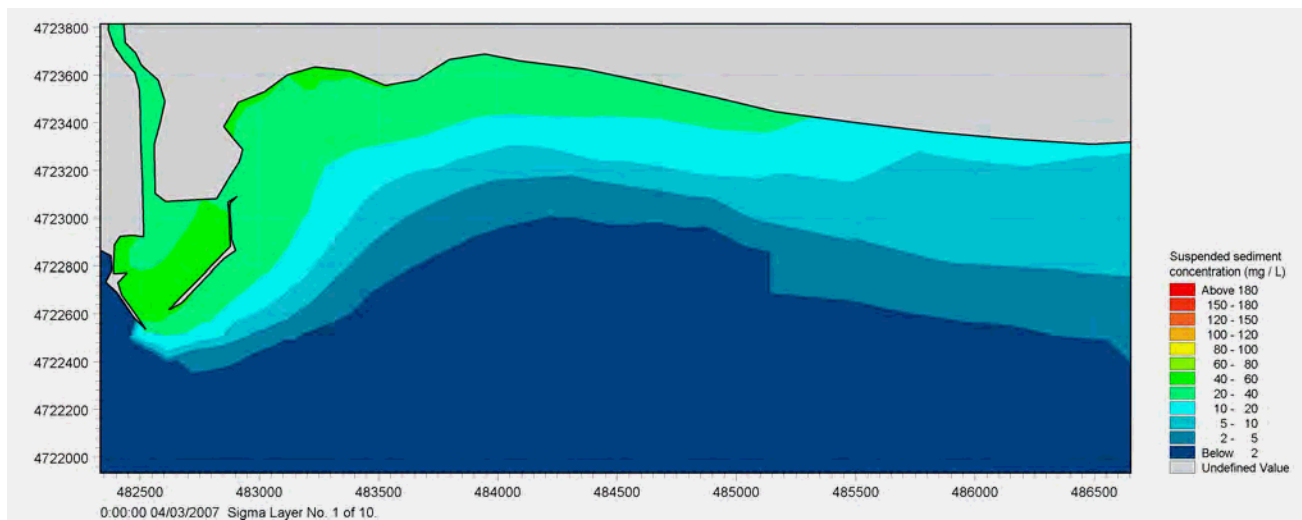


(c)

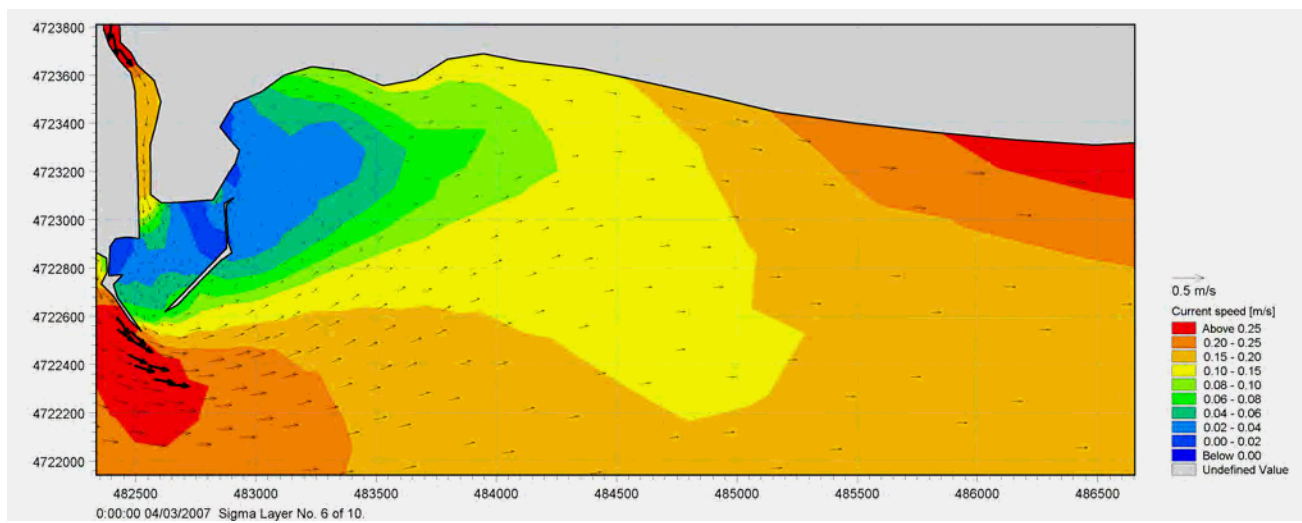
Figure 16f. Release 1 ; Snapshot 6 @ [peak plume time at Kettle Creek + 12 hrs], (3 March 16:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

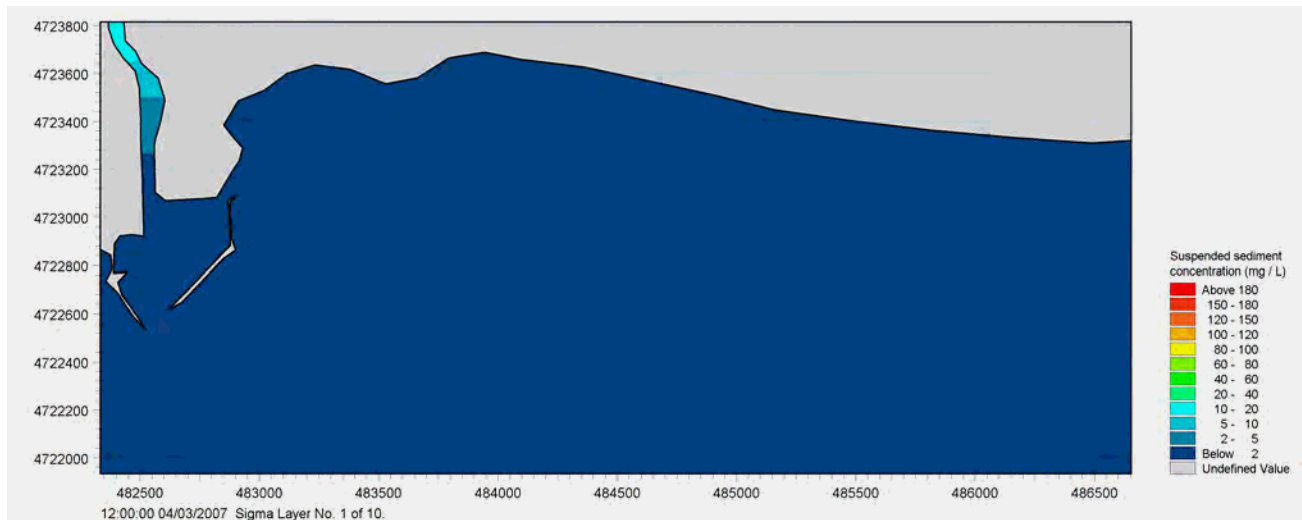


(b)

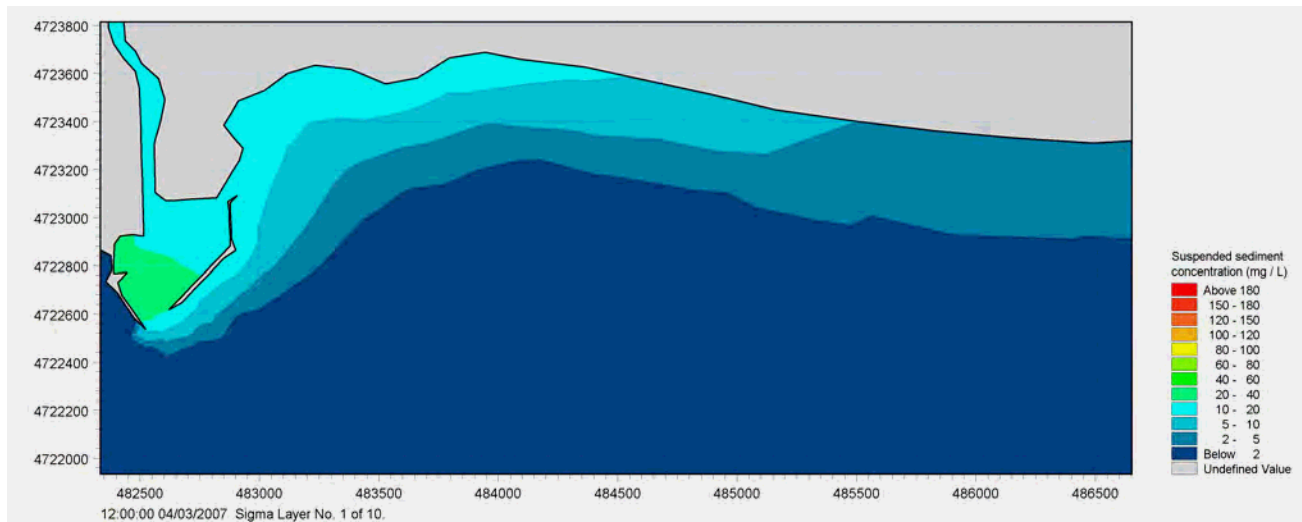


(c)

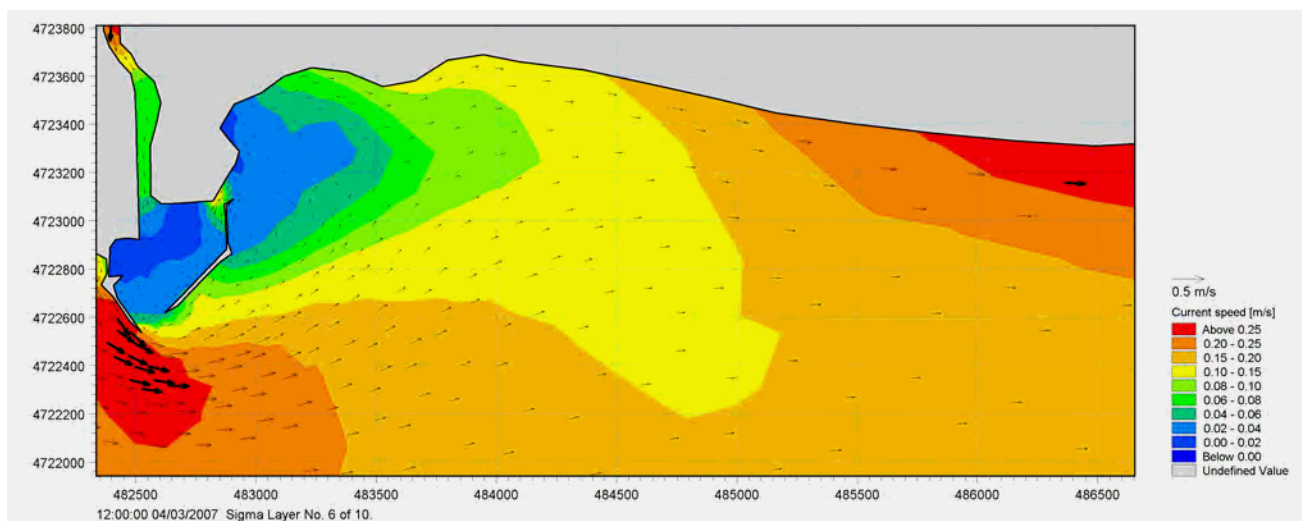
Figure 16g. Release 1 ; Snapshot 7 @ [peak plume time at Kettle Creek – 20 hrs], (4 March 00:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

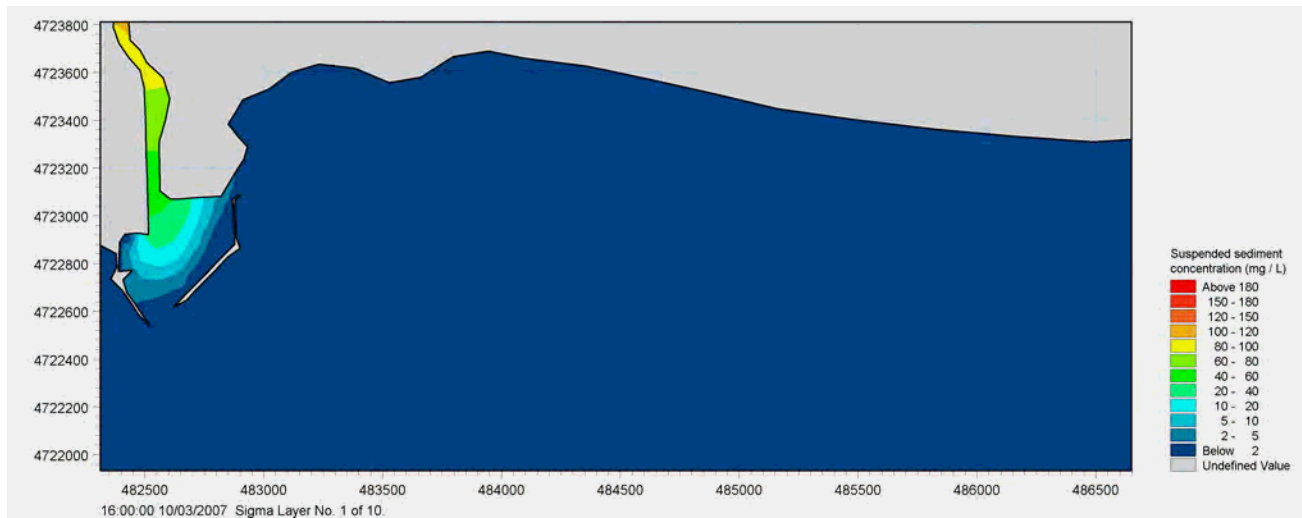


(b)

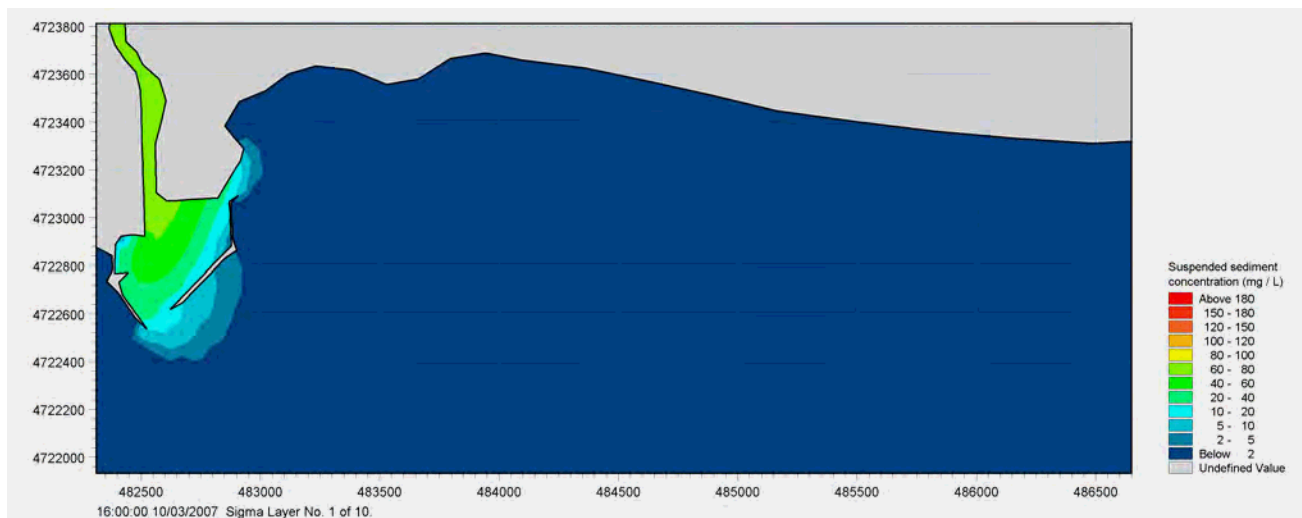


(c)

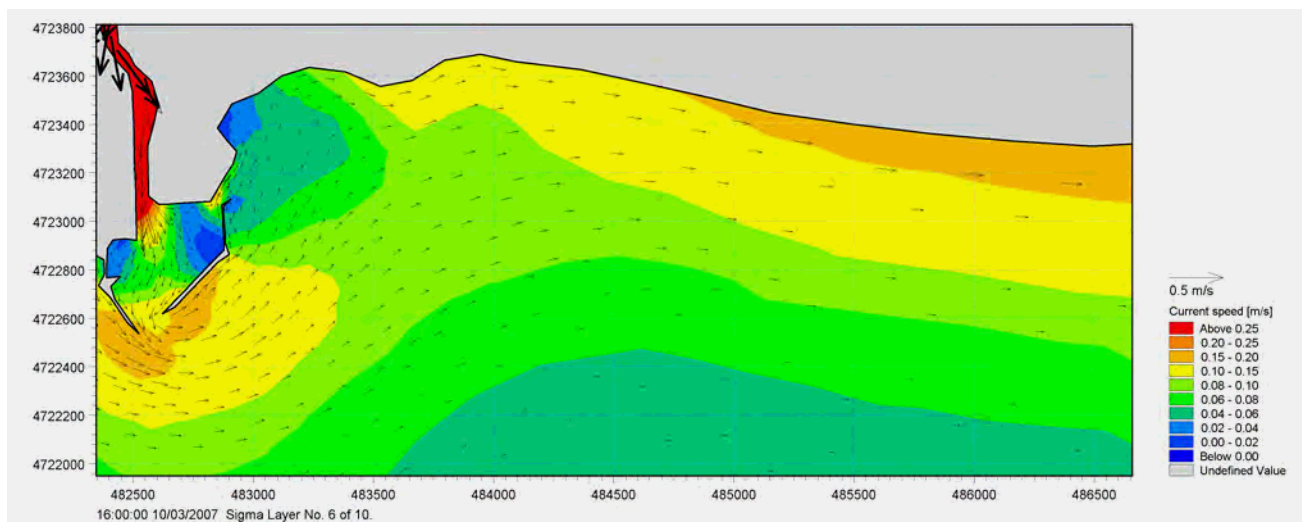
Figure 16h. Release 1 ; Snapshot 8 @ [peak plume time at Kettle Creek + 32 hrs], (4 March 12:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

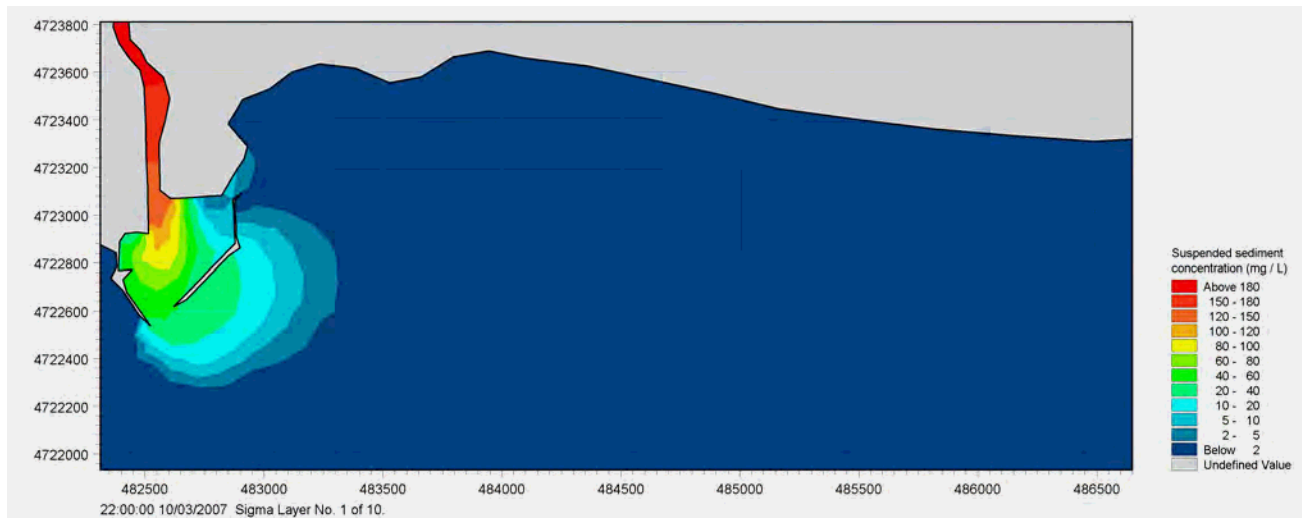


(b)

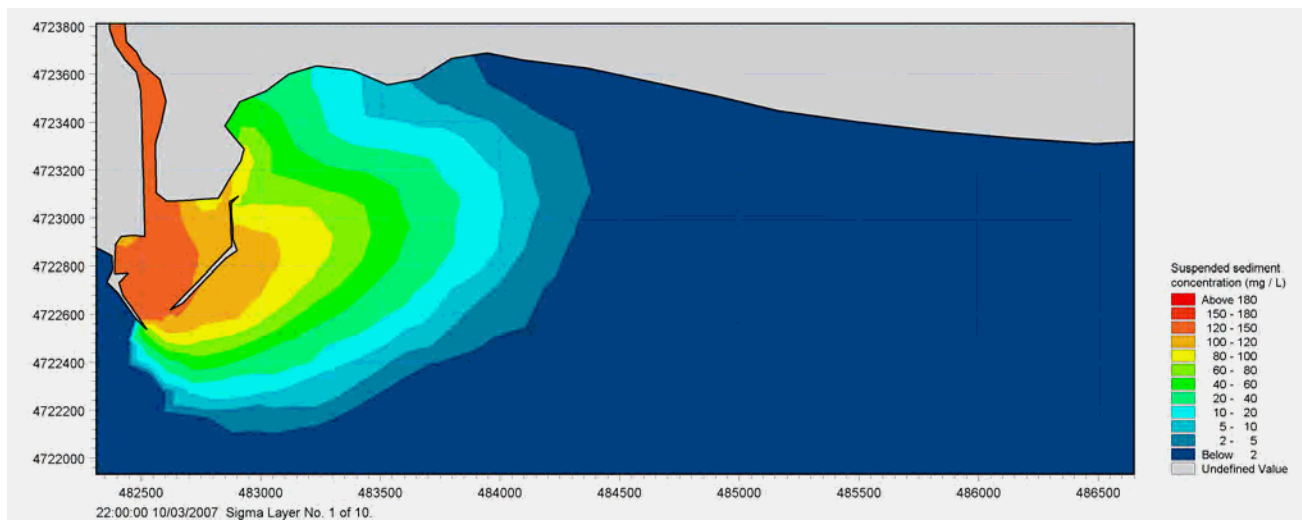


(c)

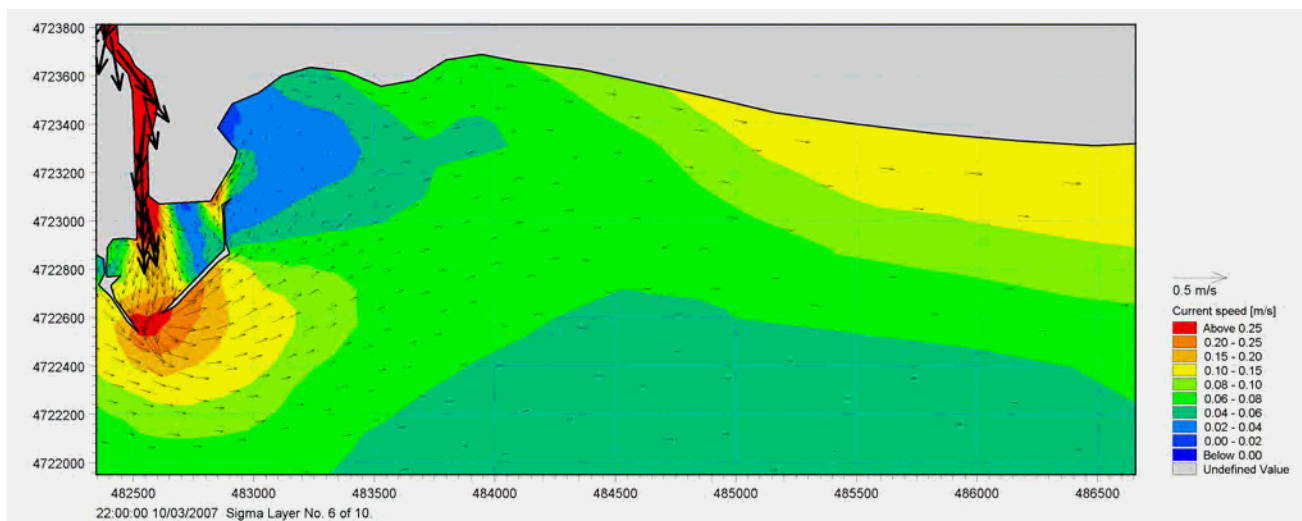
Figure 17a. Release 2 ; Snapshot 1 @ [peak plume time at Kettle Creek – 12 hrs], (10 March 16:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

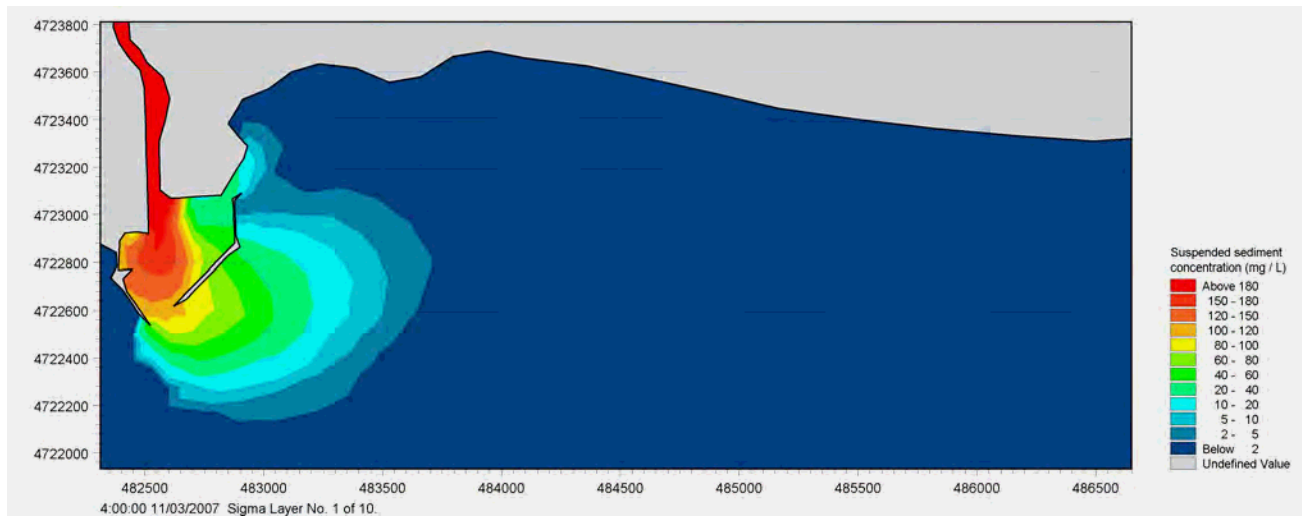


(b)

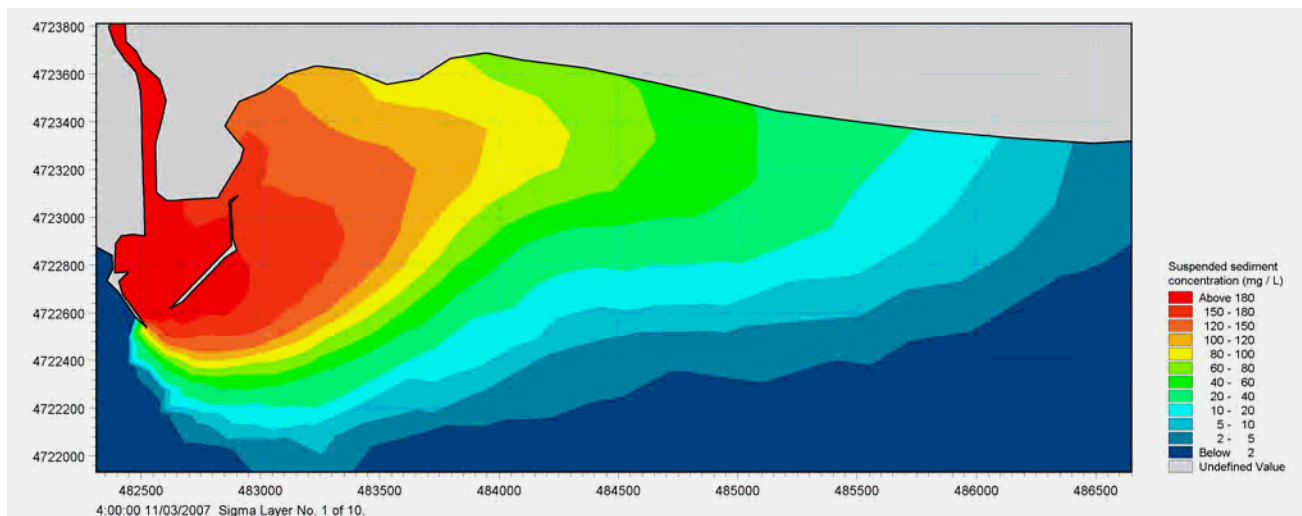


(c)

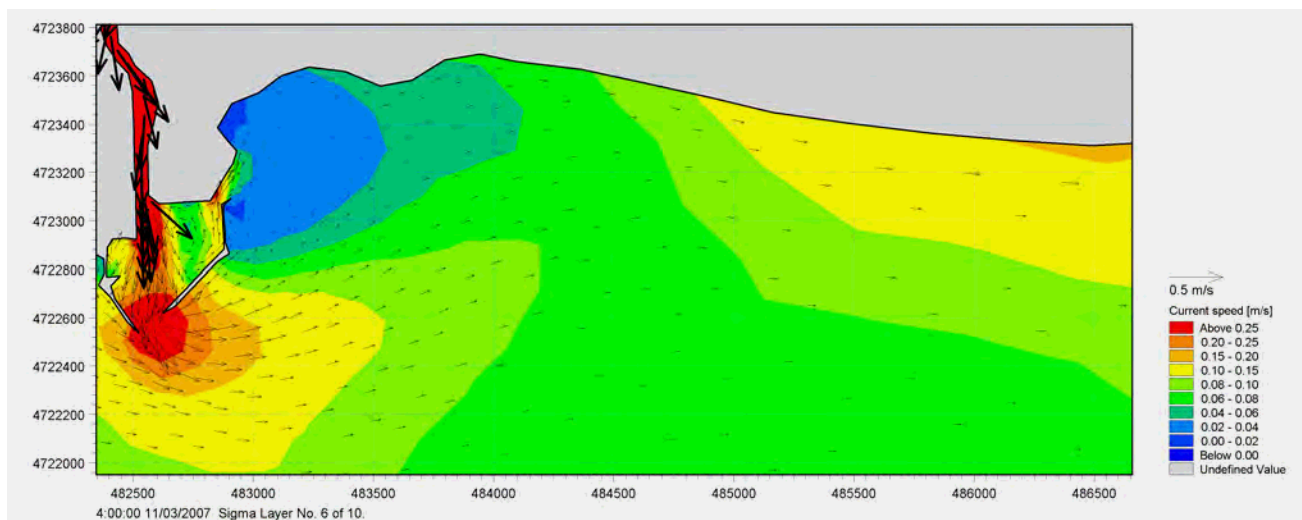
Figure 17b. Release 2 ; Snapshot 2 @ [peak plume time at Kettle Creek – 6 hrs], (10 March 22:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

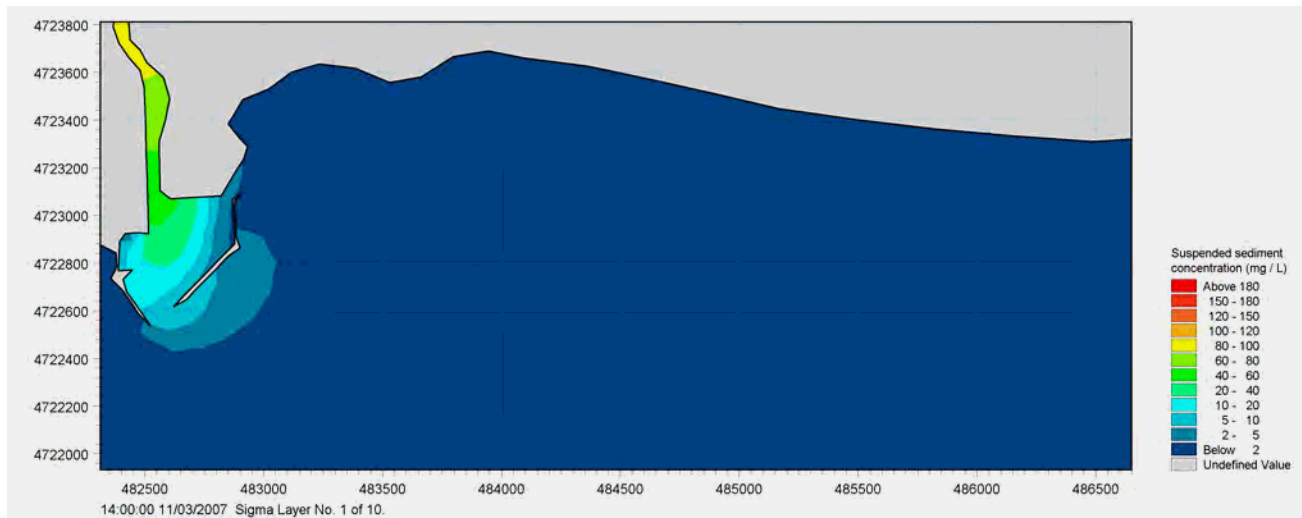


(b)

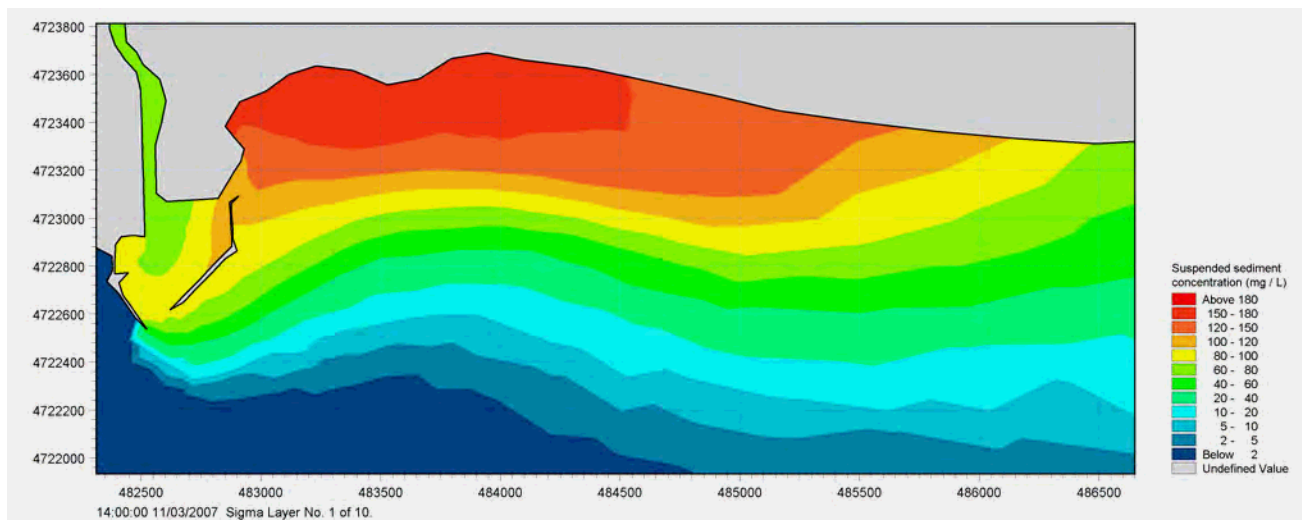


(c)

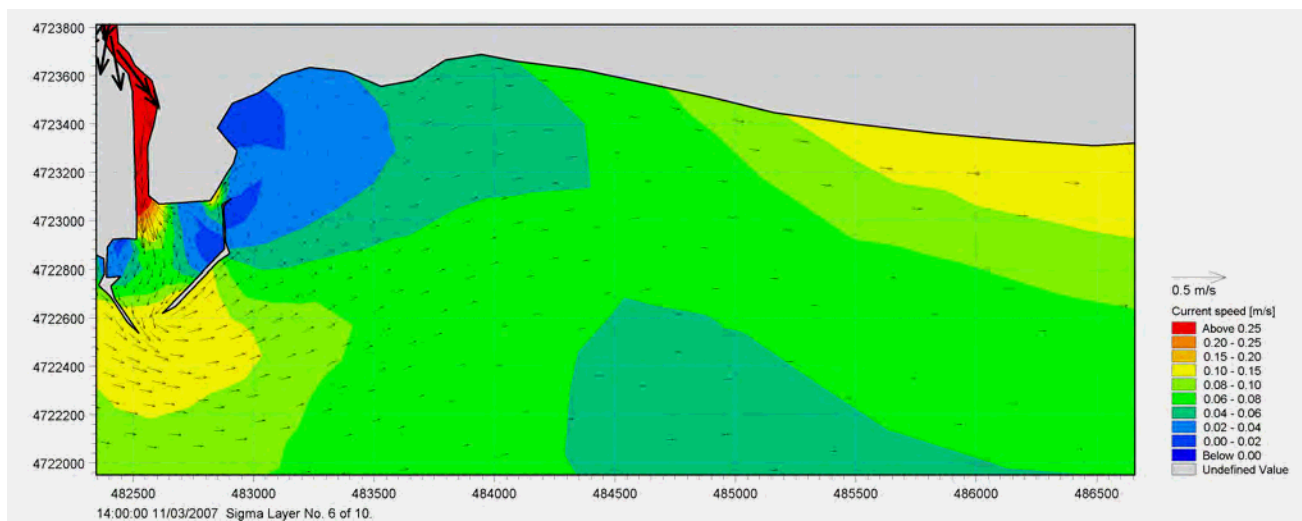
Figure 17c. Release 2 ; Snapshot 3 @ [peak plume time at Kettle Creek], (11 March 04:00).
Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

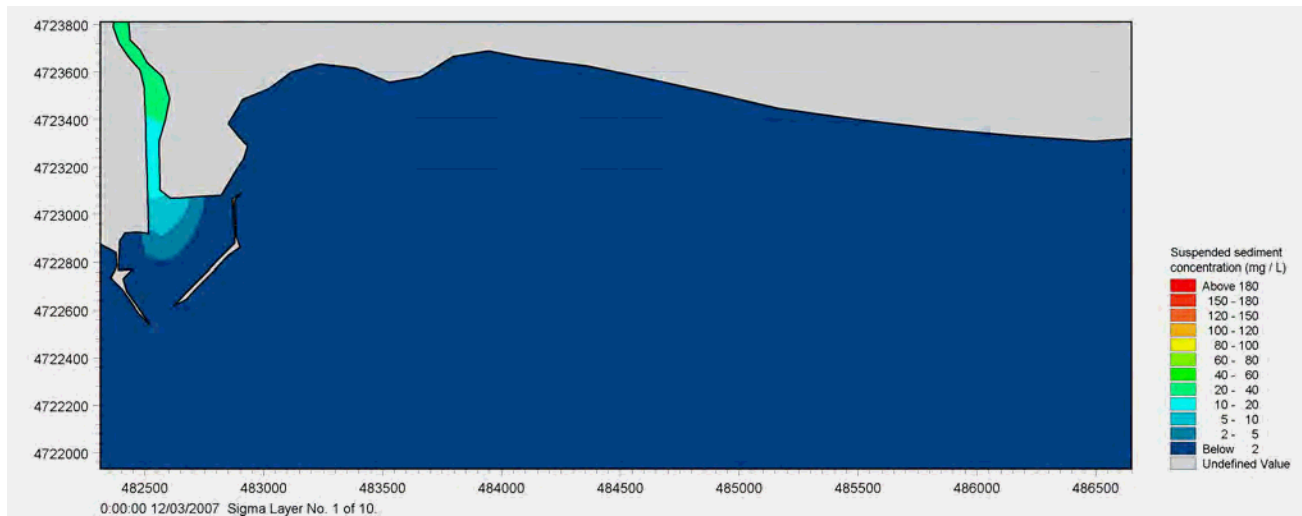


(b)

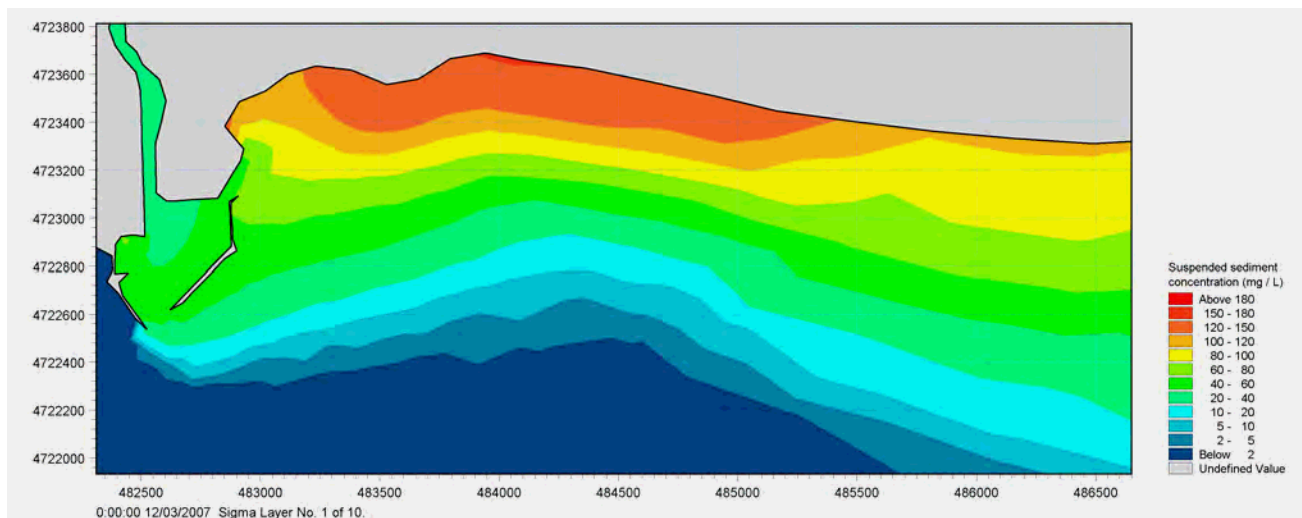


(c)

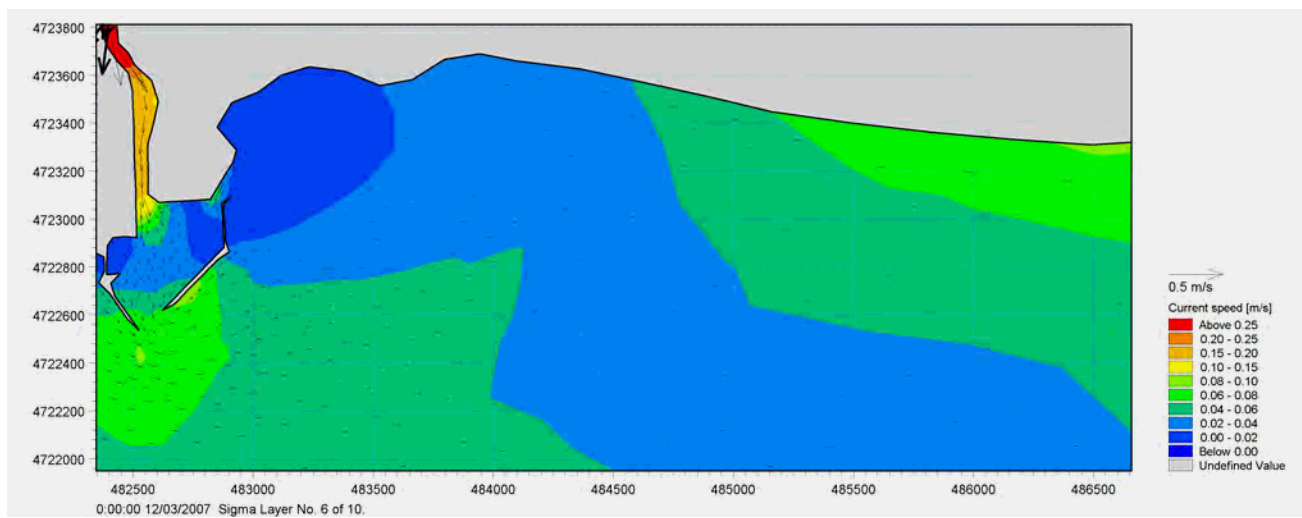
Figure 17d. Release 2 ; Snapshot 4 @ [peak plume time at Kettle Creek + 10 hrs], (11 March 14:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

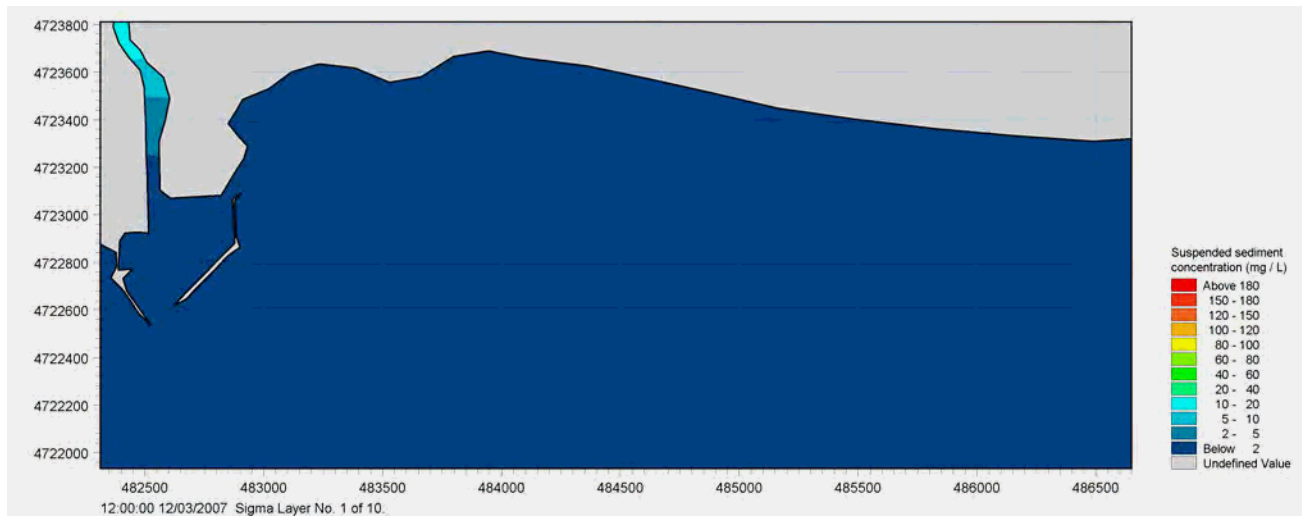


(b)

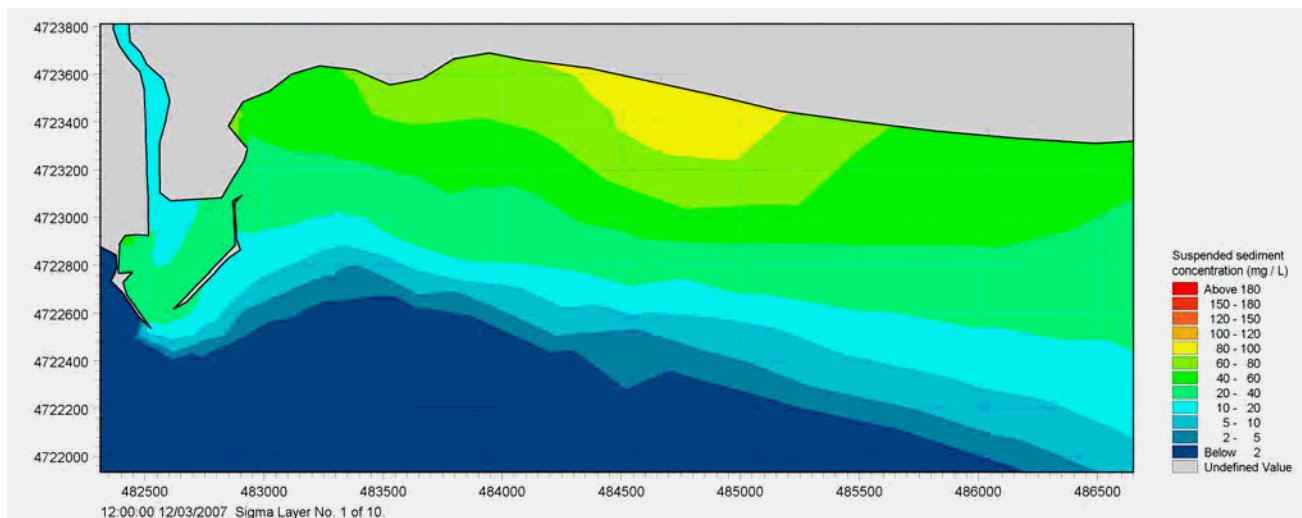


(c)

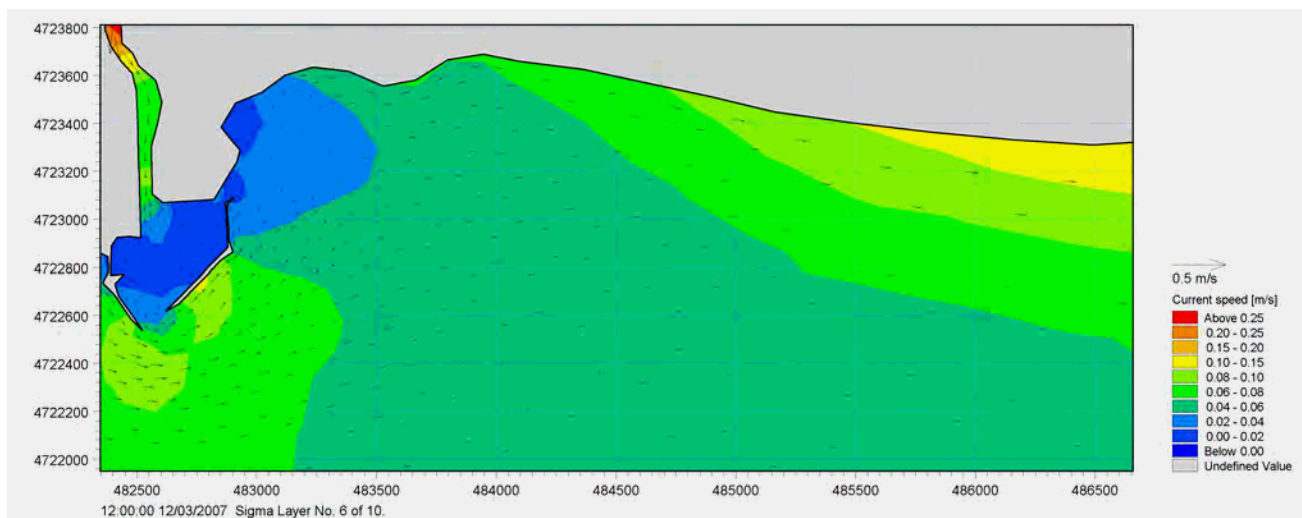
Figure 17e. Release 2 ; Snapshot 5 @ [peak plume time at Kettle Creek + 20 hrs], (12 March 00:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

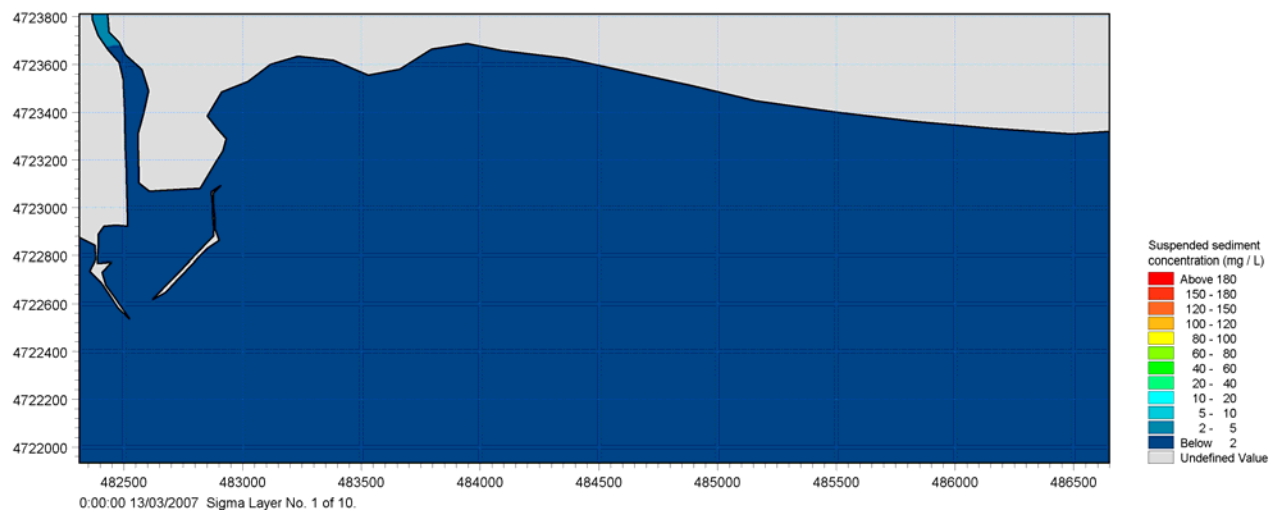


(b)

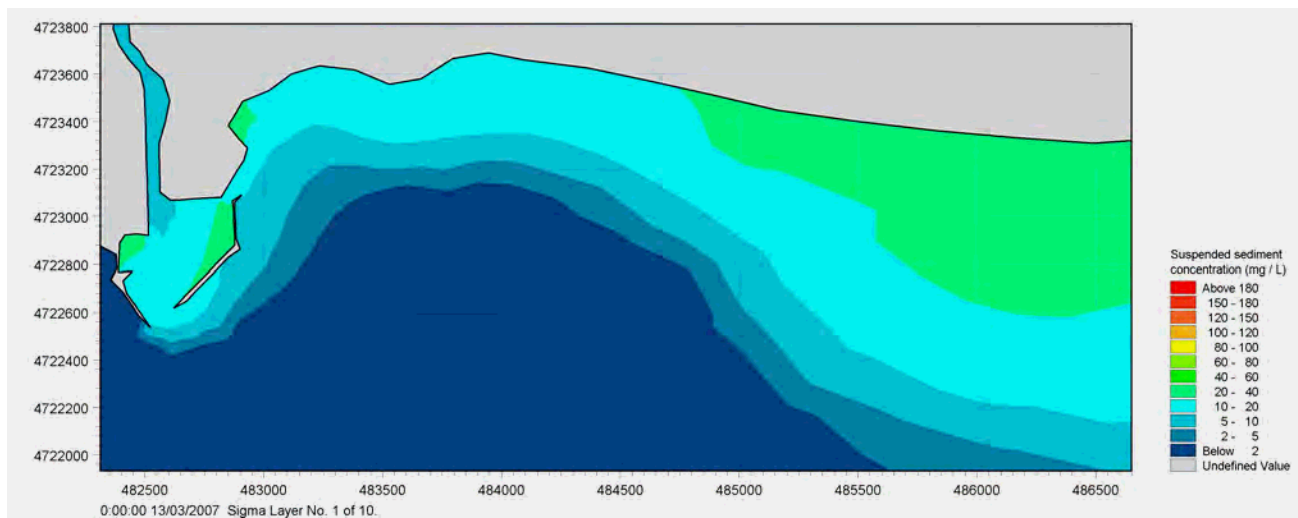


(c)

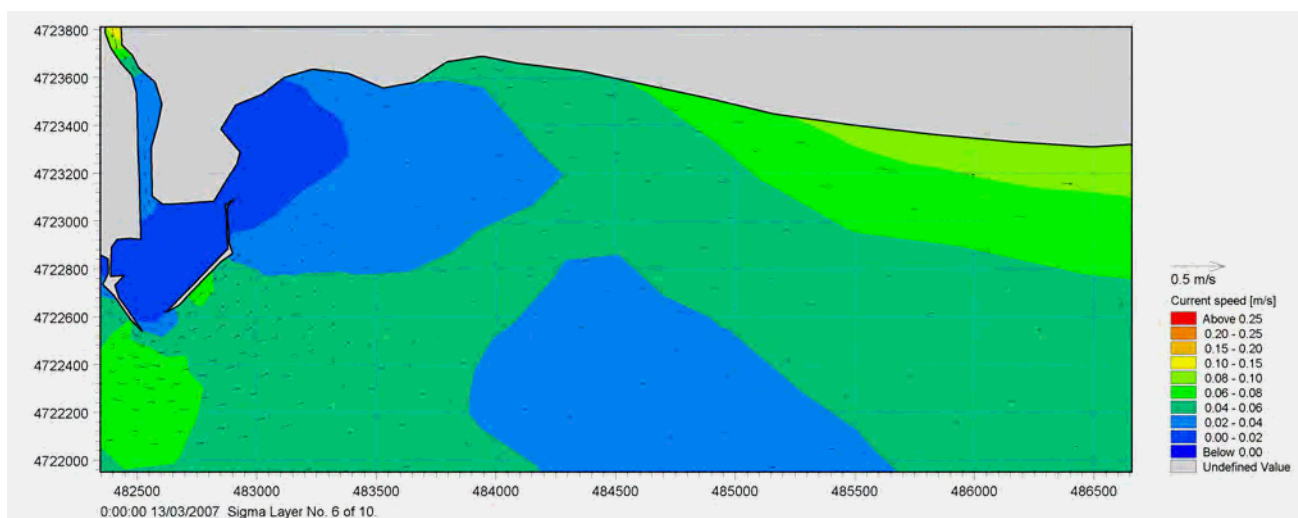
Figure 17f. Release 2 ; Snapshot 6 @ [peak plume time at Kettle Creek + 32 hrs], (12 March 12:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)

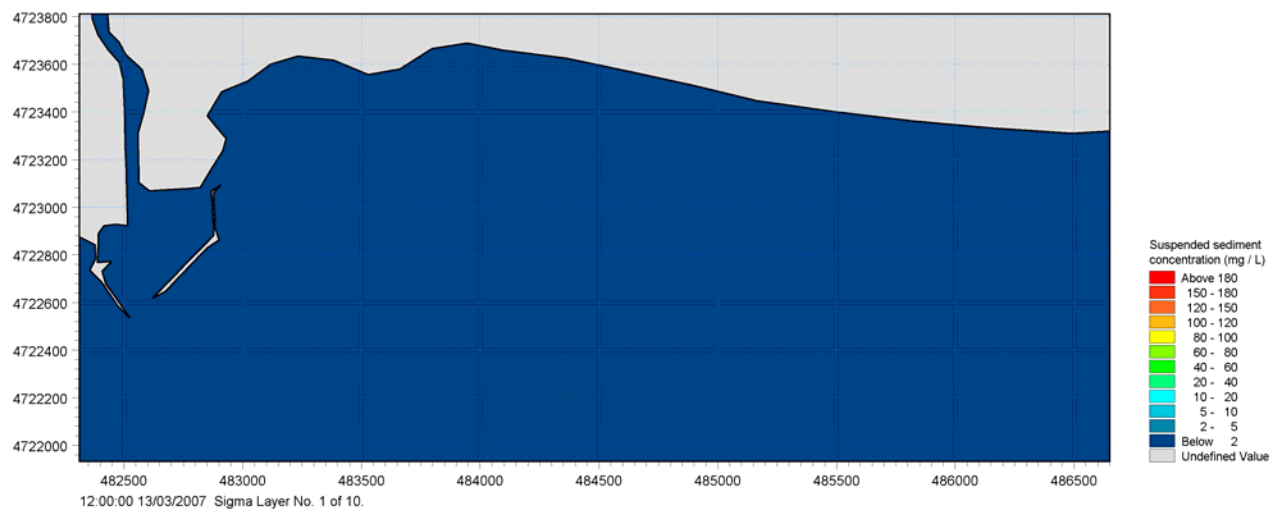


(b)

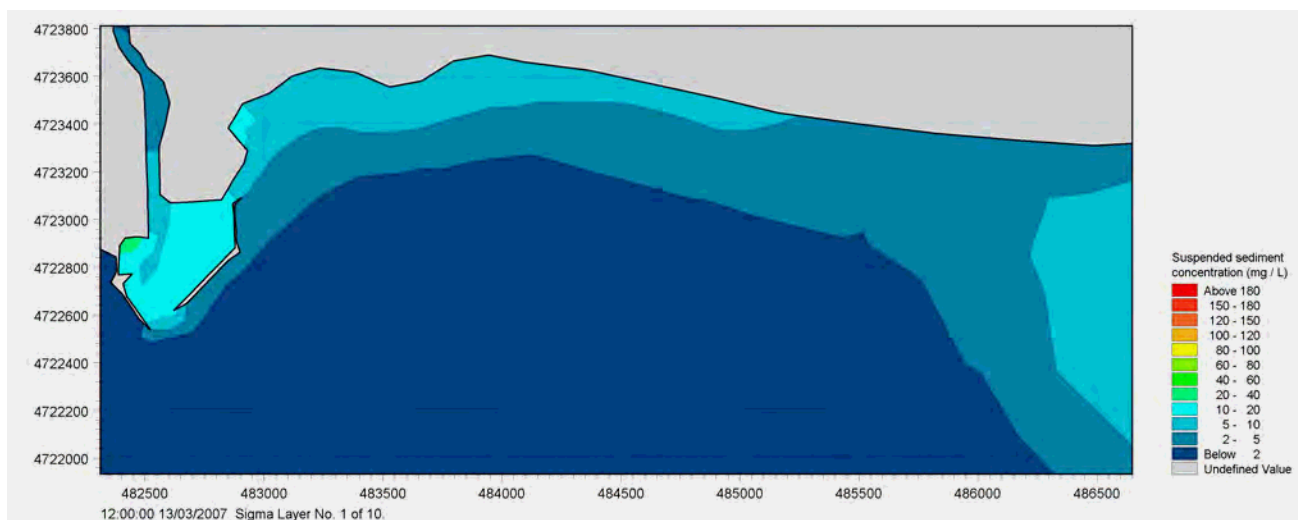


(c)

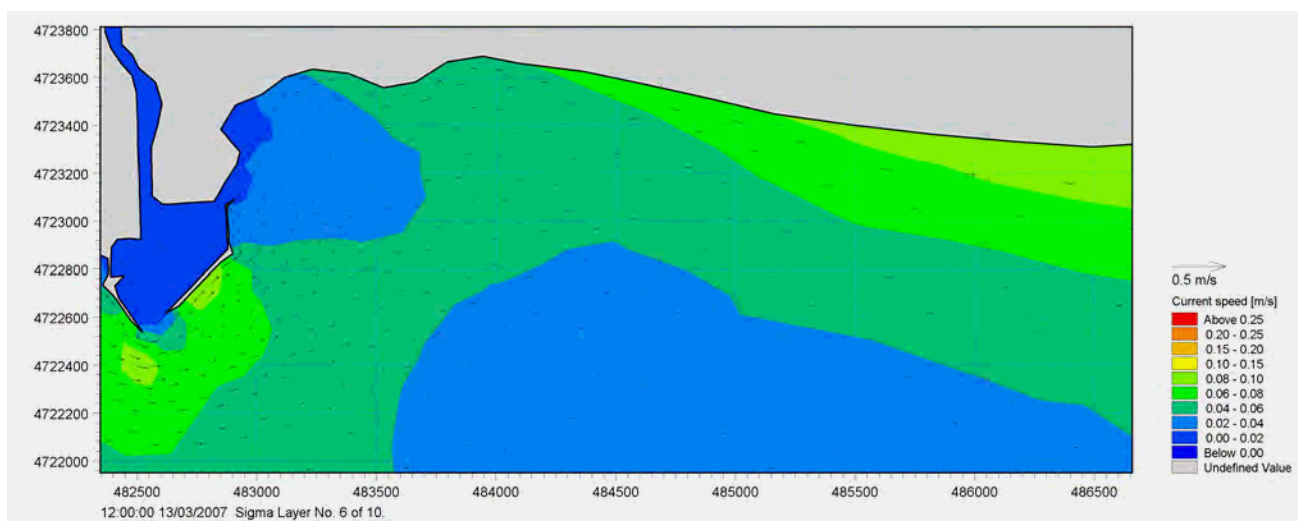
Figure 17g. Release 2 ; Snapshot 7 @ [peak plume time at Kettle Creek + 44 hrs], (13 March 00:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).



(a)



(b)



(c)

Figure 17h. Release 2 ; Snapshot 8 @ [peak plume time at Kettle Creek + 56 hrs], (13 March 12:00). Concentration of suspended sediment in bottom layer of water column, (mg/L), assuming the behaviour of: fine sand (plot a), and no loss (plot b). Water velocity, (in m/s), near mid-depth of water column (plot c).

